TECHNICAL REPORT

MFL Establishment for the Waccasassa River, Estuary and Levy (Bronson) Blue Spring

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PROFESSIONAL

CERTIFICATION

I certify that all Engineering work performed for the "MFL Establishment for the Waccasassa River, Estuary and Levy (Bronson) Blue Spring" prepared for the Suwannee River Water Management District Department Of Water Resources Report WR 03/04-128 was prepared under my direct supervision.

I certify that all Geologic and Hydrogeologic work performed for the "MFL Establishment for the Waccasassa River, Estuary and Levy (Bronson) Blue Spring" prepared for the Suwannee River Water Management District Department Of Water Resources Report WR 03/04-128 was prepared under my direct supervision.

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TABLE OF CONTENTS

APPENDICES:

LIST OF FIGURES

LIST OF TABLES

TAB 1

1.0 Introduction

This technical report (Report) presents the data and analyses that provide technical support for the establishment and adoption of Minimum Flows and Levels (MFLs) for the Waccasassa River and Levy Blue Spring (Figure 1-1). The goals for these MFLs are:

- To satisfy the requirements of state water law and policy and
- To implement the intent and policy of the Governing Board (Board) of the Suwannee River Water Management District (District).

1.1 Florida Law Concerning MFL Establishment

Chapter 373.042, Florida Statutes (F.S.) specifies that:

> (1) Within each section or the water management district as a whole, the Florida Department of Environmental Protection (Department) or the District Board shall establish the following:
>
> (a) Minimum flow for all surface watercourses in the area. The minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area.
>
> (b) Minimum water level. The minimum water level shall be the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area.

Subsequent language in the statute (Chapter 373.042(1), F.S.) provides guidance that the Governing Board shall use the “best information available” and that it may consider “seasonal variations” and the “protection of non-consumptive uses” in establishing MFLs.

Additional policy guidance is provided in the State Water Resources Implementation Rule regarding MFLs (Chapter 62-40.473, Florida Administrative Code [F.A.C.]), indicating that “ . . . consideration shall be given to the protection of water resources, natural seasonal fluctuations in water flows or levels, and environmental values associated with coastal, estuarine, aquatic, and wetlands ecology. . . .” These environmental values may include:

a) Recreation in and on the water;

b) Fish and wildlife habitats and the passage of fish;

c) Estuarine resources;

d) Transfer of detrital material;

e) Maintenance of freshwater storage and supply;

f) Aesthetic and scenic attributes;

g) Filtration and absorption of nutrients and other pollutants;

h) Sediment loads;

i) Water quality; and

j) Navigation.

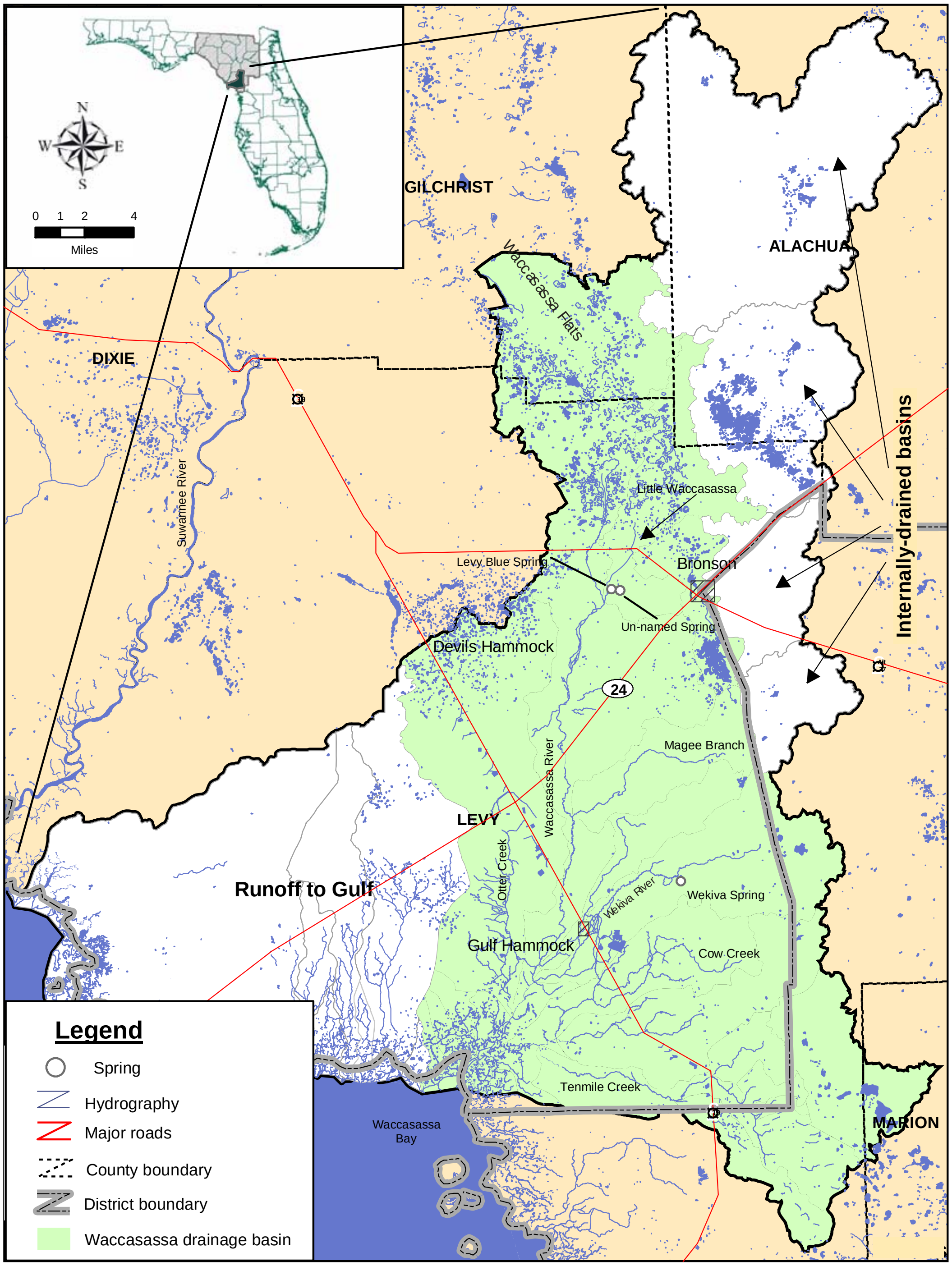

Figure 1-1. Waccasassa River MFL study area and total extent of the Waccasassa Hydrologic Unit. Areas in green constitute the Waccasassa River drainage basin while areas in white are part of the USGS hydrologic unit but are not part of the river basin.

These requirements constitute the statutory framework and the outline for the scope of work to establish MFLs for the Waccasassa River.

In the fall of 2004 the District Board targeted development of MFLs for the Waccasassa River and Levy Blue Spring for 2006. The study area (Figure 1-1) included those portions of the Waccasassa River drainage basin in Gilchrist and Levy counties, Florida. Note that the U.S. Geological Survey (USGS) Waccasassa Hydrologic Unit (Kenner et al., 1967; U.S. Geological Survey, 1974) includes both the river basin and regions east and west of the river basin that either drain directly to the Gulf of Mexico or are internally drained. The river basin, which is shown in green on Figure 1-1, constitutes the study area for which MFLs are proposed in this report. Areas shown in white in Figure 1-1 include regions within the hydrologic unit, but outside of the river drainage basin.

1.2 Water Body Overview and Designated Protected Areas

The Waccasassa River is a scenic and relatively undeveloped river within Florida. It has several interesting characteristics that add to its importance. The river begins in the Waccasassa Flats (Figure 1-1), a broad complex of swamps and pine flatwoods located in northern and central Gilchrist County. Low permeability sediments underlie the Waccasassa Flats, so rainfall forms swampy areas and runoff is directed toward the margins of the Flats where several rivers and streams originate. The Waccasassa River becomes a named hydrographic feature in the swamps of extreme southern Gilchrist County. Throughout most of the course of the river, it flows through woodlands and swamps, and the drainage system is complicated with multiple channels and areas of sheet flow (i.e., Devil's Hammock in northern Levy County; Figure 1-1). Southwest of US 19 in Levy County, the river becomes tidal with a wide floodplain before it empties into a broad, shallow estuary known as the Waccasassa Bay (Figure 1-1).

Major tributaries (Figure 1-1) include Cow Creek, Tenmile Creek, Wekiva River, and McGee Branch. The Wekiva and Waccasassa Rivers receive significant inflows from two named springs.

Wekiva Springs, three interconnected springs located approximately 4.5 miles northeast of Gulf Hammock (Figure 1-1), supplies water to the Wekiva River. An historic second magnitude spring (Roseneau et al., 1977), Wekiva Springs is located on private property and is a source of bottled water. A county park, Henry Beck Park, is located on the Wekiva River downstream from the springs.

Levy Blue Spring (Bronson Blue Spring), an historic third magnitude spring (Roseneau et al., 1977; Scott et al., 2004), is located within a county park near Bronson, the county seat of Levy County. Levy Blue Spring is located on publicly owned lands and is on the MFL priority list for the District. Levy Blue Spring is an important source of flow in the Waccasassa River. The spring run from Levy Blue Spring empties into a small tributary of the Waccasassa known as the Little Waccasassa River.

The Levy Blue Spring property and junction with the Little Waccasassa are at the north (upstream) end of the reach of the Waccasassa that lies within the Devils Hammock Wildlife Management Area (WMA). The Devils Hammock WMA is managed cooperatively by the District, Levy County, and the Florida Fish and Wildlife Conservation Commission. Consisting of over 7,000 acres, the WMA is a popular area for hunting, fishing, and canoeing.

The Waccasassa River is widely regarded as a river system with high conservation value. Existing state designations recognize the Waccasassa and its estuary as a river system of both regional and statewide importance. The Waccasassa River has been designated an

Outstanding Florida Water (OFW; Chapter. 62-302.700[9][i][34], F.A.C.). This designation is conferred to waters of the state with "exceptional recreational or ecological significance" (Chapter 62-302.700[3], F.A.C.).

The estuary includes the Waccasassa Bay Preserve State Park. This 34,000-acre park is the sixth largest in the state. The park is a popular fishing and boating area, although land-based activities are limited owing to access issues. The estuary is also part of the Big Bend Seagrasses Aquatic Preserve, which extends northward from the Waccasassa estuary.

1.3 Relevant Water-Resource Values

As noted in Section 1.1, Chapter 62-40.473, F.A.C. provides policy guidance regarding establishment of MFLs. In particular, this section of Florida's Water Policy lists ten specific environmental and water-resource values that should be considered in setting MFLs. Some are more relevant to the study area than others.

As part of the District's MFL-establishment process, environmental and water-resource values evaluation matrices are prepared to identify potential target values, as defined by Chapter 62-40.473 F.A.C., that may be the limiting factors for the proposed MFLs (Table 1-1). This process serves to focus the evaluation and shape the types of analyses needed to complete the MFL process. This ranking process is initiated after compilation and review of all available data. Each ranking is based upon review of the available data and the collective experience of the evaluation team in establishing MFLs. While all water-resource values are considered throughout the MFL investigation, target values are those that potentially have the highest probability of limiting the amount of water available for the water body without causing significant harm. As an example, if the fish passage criterion requires the most water flow to avoid significant harm to the water body, then that value becomes the limiting factor for the proposed MFL, since all other values would require less flow to avoid significant harm. This value ranking procedure is flexible and new target criteria can emerge during the evaluation process. In most cases the initial determinations have proven to be accurate.

1.3.1 Application of Resource Values to the Waccasassa River and Estuary

The relevance of each resource value, and how it was incorporated into the establishment of MFLs for the Waccasassa River are discussed below:

a. Recreation in and on the water. This water-resource value is considered relevant to the Waccasassa River. The upper, perennial reaches of the river are utilized for canoeing and kayaking, hunting, and fishing. District lands adjacent to the river provide access for hiking and other outdoor activities. In establishing MFLs for the Waccasassa River, general information was considered on the economic value of ecotourism, recreational fishing, and related activities.

b. Fish and wildlife habitats and the passage of fish. This water-resource value is considered relevant for the Waccasassa River MFLs. Because of the extensive wetlands and floodplain of the lower river and estuary, fish movement is important for population stability. Manatee enter the lower river and estuary on a periodic basis, but the river is not a recognized manatee refuge (i.e., it has not been listed as a primary or secondary thermal refuge by the Warm-Water Task Force (2004). This is because of the springs that discharge to the river are inland and do not develop a thermal plume in the lower river and estuary. Therefore, manatees were not considered under fish and wildlife habitat and passage of fish.

c. This water-resource value is relevant to the Waccasassa River MFLs, and existing data in the scientific literature were used to assist in determination of MFLs for the Waccasassa River.

d. Estuarine resources. This water-resource value is considered relevant for the Waccasassa River system. The Waccasassa River estuary is the downstream portion of the study area and includes the Waccasassa Bay Preserve State Park and portions of the Big Bend Seagrasses Aquatic Preserve. This water-resource value is relevant to the Waccasassa River MFLs and existing data in the scientific literature were used to assist in the determination of MFLs for the Waccasassa River.

e. Transfer of detrital material. It is well established that a principal food base in aquatic and wetland ecosystems is decaying plant material, collectively termed “plant detritus” or simply detritus. Transport of this material from the extensive river floodplain wetlands to the river channel is an important source of food material for riverine and estuarine taxa. This water-resource value is relevant to the Waccasassa River MFLs, and existing data in the scientific literature were used to assist in determination of MFLs for the Waccasassa River.

f. Maintenance of freshwater storage and supply. This water-resource value refers to the long-term maintenance (i.e., sustainability) of water storage and supply capability of the water body. The result of the protection of this value by MFL establishment is to ensure that, over time, the ability of the water body to serve as a supply source for existing and future legal permitted users is preserved without causing “significant harm” to the water resource or ecology of the area. This water-resource value is considered relevant to the Waccasassa River MFLs and is discussed in more detail in Chapter 3. Establishment of an MFL for a water body implicitly establishes potential availability of that water through the permitting process.

g. Aesthetic and scenic attributes. This water-resource value is closely linked with recreation in that part of the recreational value for the Waccasassa River is the aesthetic experience. Aesthetic and scenic attributes are considered relevant to the establishment of MFLs for the Waccasassa River and were incorporated as an important characteristic along with recreation.

h. Filtration and absorption of nutrients and other pollutants. This water-resource value is considered relevant to the Waccasassa River MFL. The role of wetlands in maintenance of water quality is well established (Mitsch and Gosselink, 1986). By allowing for settlement of suspended particulates, uptake of nutrients by plants, and sequestration of heavy metals and other contaminants in sediments, wetlands help protect water quality. Data from the scientific literature on nutrient cycling and other biochemical functions of wetlands were taken into consideration in establishing MFLs, with the assumption that maintaining an acceptable level of ecological integrity for wetland ecosystems of the Waccasassa River would maintain this particular function.

i. Sediment loads. This water-resource value is considered marginally relevant to the Waccasassa River MFL. Available evidence indicates that the Waccasassa carries minor sediment loads. Sediment transport is important in the maintenance of geomorphic features (bed forms) and their associated ecological communities in the lower river. General information from the literature on riverine fluvial dynamics was considered in setting the MFLs.

j. Water quality. This water-resource value is considered relevant to setting MFLs on the Waccasassa River. Because of the OFW designation of the river, water quality is of concern, especially with respect to flushing of wetlands, maintenance of dissolved oxygen, color, and turbidity, and salinity within tidal and estuarine portions of the system. The response of important aquatic habitats and fauna to surface-water quality was also considered.

k. Navigation. This water-resource value was not considered to be relevant to the Waccasassa River MFLs, in that the system is not a waterway that supports commercial shipping or barge traffic. Passage by recreational vessels, canoes, etc. was considered under the "Recreation in and on the water" value above.

Table 1-1

MFL DECISION MATRIX: WACCASASSA RIVER AND ESTUARY

Potential Criteria	Resource at Risk	Resource Value	Legal Factors	Rank	Available Data	Preliminary Data Analysis: Related to Flow?	Limiting Criterion?
Notes	1	2	3	4	5	6	7
Recreation in and on the water	1	2	2	5	1	Y	N
Fish and wildlife habitats and the passage of fish	2	3	3	8	1	Y	N
Estuarine resources	2	3	3	8	2	Y	Y
Transfer of detrital material	1	1	1	3	1	Y	N
Maintenance of freshwater storage and supply	2	2	2	6	2	Y	N
Aesthetic and scenic attributes	1	2	3	6	1	Y	N
Filtration and adsorption of nutrients and other pollutants	1	1	1	3	1	Y	N
Sediment loads	2	2	1	5	1	Y	N
Water quality	2	3	1	6	2	Y	N
Navigation	1	1	1	3	1	NA	N

Notes:

1. Evaluation of the level to which the resource is at risk. 1 = low risk, 2 = medium risk, 3 = high risk
2. Evaluation of importance of the criterion with respect to resource. 1 = low importance, 2 = medium importance, 3 = highly important
3. Legal constraints on resource, such as endangered species, Outstanding Florida Water, etc. 1 = low, 2 = medium, 3 = high
4. Sum of columns 1, 2, and 3. Indicates overall importance of criterion to MFL development.
5. Evaluation of available data for use in development of MFL based on the criterion. 0 = no data available, 3 = abundant and relevant data available
6. Evaluation as to whether criterion is related to flow or level in resource. (Yes or No)
7. Evaluation as to whether criterion is potentially limiting for MFL development. (Yes or No)

Based on the preliminary screening (Table 1-1), the following resources were investigated to identify the limiting conditions for MFL development for the Waccasassa River and estuary:

- Fish and wildlife habitats and the passage of fish,
- Estuarine resources,
- Maintenance of freshwater storage and supply,
- Aesthetic and scenic attributes, and
- Water quality.

As shown in the right-hand column of Table 1-1, the final MFLs were based on estuarine resources. This is partly in recognition of the value of the estuary as habitat and partly because protection of flow sufficient to maintain the estuary appears to protect the other resources.

1.3.2 Application of Resource Values to Levy Blue Spring

The relevance of each resource value and how it was incorporated into the establishment of MFLs for Levy Blue Spring are discussed below:

a. Recreation in and on the water. This water-resource value is considered relevant to Levy Blue Spring. As a county park, the spring is an important recreational resource to the county and region. In establishing MFLs for Levy Blue Spring, general information was considered on the economic value of ecotourism, recreational bathing, and related activities.

b. Fish and wildlife habitats and the passage of fish. This water-resource value is considered of marginal relevancy with respect to Levy Blue Spring MFLs because of the highly modified spring bowl and lack of fish and wildlife habitat within the spring. Fish and wildlife criteria are dealt with in the MFL for the river itself.

c. Estuarine resources. Because of its contribution to flow in the Waccasassa River, this water-resource value is relevant for Levy Blue Spring. The role of Levy Blue Spring in supporting the estuary is dealt with through adoption of MFLs for the river and the spring.

d. Transfer of detrital material. Levy Blue Spring is not a significant source of detritus. Therefore, transfer of detrital material was not considered in MFL development.

e. Maintenance of freshwater storage and supply. This water-resource value refers to the long-term maintenance (i.e., sustainability) of water storage and supply capability of the water body. The result of the protection of this value by MFL establishment is to ensure that, over time, the ability of the water body to serve as a supply source for existing and future legal permitted users is preserved without causing “significant harm” to the water resource or ecology of the area. This water-resource value is considered relevant to Levy Blue Spring MFLs and is discussed in more detail in Chapter 3.

f. Aesthetic and scenic attributes. This water-resource value is closely linked with recreation, in that part of the recreational value for Levy Blue Spring is the aesthetic experience. Aesthetic and scenic attributes were considered relevant to the establishment of MFLs for Levy Blue Spring and were incorporated as an important characteristic along with recreation.

g. Filtration and absorption of nutrients and other pollutants. This water-resource value is not considered relevant to Levy Blue Spring MFL. The spring plays a minor role in nutrient and other pollutant fixation. Flushing of the spring to maintain water quality for swimming was considered through use of best available literature and the Florida Administrative Code.

h. Sediment loads. This water-resource value is not considered relevant to Levy Blue Spring. The spring is not a significant source of sediment.

i. Water quality. This water-resource value is considered potentially relevant to setting MFLs for Levy Blue Spring. Nitrate, the primary analyte of concern in spring water, was less than 1 mg/L in 2002 (Scott, et al., 2004). This concentration may have an influence on local aquatic habitats and recreational use of the spring. MFLs have a limited ability, if any, to assist in controlling nutrients in water discharge from springs, but potentials for use of MFLs were considered.

j. Navigation. This water-resource value was not considered to be relevant to Levy Blue Spring MFLs in that the system is not a waterway that supports commercial shipping or barge traffic.

Based on the preliminary screening (Table 1-2), the following resources were investigated to identify the limiting conditions for MFL development for Levy Blue Spring:

- Recreation in and on the water,
- Maintenance of freshwater storage and supply,
- Aesthetic and scenic attributes, and
- Water quality.

Table 1-2

MFL DECISION MATRIX: LEVY BLUE SPRING

Potential Criteria	Resource at Risk	Resource Value	Legal Factors	Rank	Available Data	Preliminary Data Analysis: Related to Flow?	Limiting Criterion?
Notes	1	2	3	4	5	6	7
Recreation in and on the water	3	3	2	8	1	Y	Y
Fish and wildlife habitats and the passage of fish	1	1	1	3	1	Y	N
Estuarine resources	1	1	1	3	1	N	N
Transfer of detrital material	1	1	1	3	1	N	N
Maintenance of freshwater storage and supply	2	3	1	6	2	Y	Y
Aesthetic and scenic attributes	3	3	2	8	1	Y	N
Filtration and adsorption of nutrients and other pollutants	1	1	1	3	1	N	N
Sediment loads	1	1	1	3	1	N	N
Water quality	2	3	1	6	2	Y	N
Navigation	1	1	1	3	1	NA	N

Notes:

1. Evaluation of the level to which the resource is at risk. 1 = low risk, 2 = medium risk, 3 = high risk
2. Evaluation of importance of the criterion with respect to resource. 1 = low importance, 2 = medium importance, 3 = highly important
3. Legal constraints on resource, such as endangered species, Outstanding Florida Water, etc. 1 = low, 2 = medium, 3 = high
4. Sum of columns 1, 2, and 3. Indicates overall importance of criterion to MFL development.
5. Evaluation of available data for use in development of MFL based on the criterion. 0 = no data available, 3 = abundant and relevant data available
6. Evaluation as to whether criterion is related to flow or level in resource. (Yes or No)
7. Evaluation as to whether criterion is potentially limiting for MFL development. (Yes or No)

TAB 2

2.0 Introduction to the Waccasassa Basin and Study Area

2.1 Location of Study Area and Drainage Basin Extent

The Waccasassa River study area is defined as those portions of the Waccasassa hydrologic unit that constitute the surface-water drainage basin of the Waccasassa River and its tributaries. The Waccasassa hydrologic unit (Conover and Leach, 1975) encompasses several hundred square miles of central Levy County and smaller portions of southern Gilchrist, southwestern Alachua, and western Marion counties (Figure 1-1). This region contains approximately 30 small sub-basins (Foose, 1981), some of which do not contribute direct runoff to the Waccasassa River. Several of these sub-basins are internally drained, while others drain directly to the Gulf of Mexico. Therefore, these sub-basins were not included in the study area. The extent of the area contributing direct run-off to the Waccasassa River (Waccasassa Basin, Figure 1-1) is approximately 400 square miles.

The Waccasassa Flats (Figure 1-1) are only partly located within the study area. This cluster of small lakes and swamps constitutes a geological area characterized by low aquifer recharge and high run-off (Vernon, 1951; Col et al., 1997). Only the lower third of the Flats drains to the Waccasassa River, while the remainder drains to streams and/or recharge areas to the west, east, and north. This is discussed further below.

2.2 Description of the Study Area

The Waccasassa River begins along the southern margin of the Waccasassa Flats (Vernon, 1951), a low, swampy region that covers much of central Gilchrist County. Within the Flats, land surface elevations typically range between 75 and 100 feet above mean sea level (msl), numerous wetlands dot the landscape, and the water table is at or near the land surface for much of the year. The high water table reflects the relative inability of groundwater to percolate downward through clay-rich soils of the underlying Pleistocene and Miocene sediments (Puri et al., 1967; Col et al., 1997).

Typically, only a very small portion of the surface flow from the Waccasassa Flats actually contributes to the flow in the Waccasassa River. This is due to the low surface gradient of the area within the Waccasassa Flats and the lack of interconnected flow paths into the upper reach of the Waccasassa River. Instead, a large portion of the surfacewater in the Flats eventually flows laterally eastward and westward to large sinkholes and closed depressions that line the edges of the area (note the parallel rows of lakes that line the Flats in Figure 1-1). At these locations, the sheet flow and shallow groundwater flows off the Flats and recharges the underlying Floridan Aquifer. Only during very heavy rainfall events or prolonged periods of heavy rainfall (e.g., el Niño events) would significant amounts of surfacewater from the Waccasassa Flats contribute to the discharge of the Waccasassa River.

The Waccasassa River becomes a distinct, well-defined channel where the Little Waccasassa River joins the Waccasassa River (Figure 1-1). The 1,600-foot long Levy Blue Spring run (Figure 2-1) discharges into the Little Waccasassa (Figure 2-2) approximately 1,100 feet upstream from its confluence with the Waccasassa River. Therefore, many consider the spring to constitute the head of the river. Historic discharge from Levy Blue Spring averages approximately 9 cfs, and the maximum-recorded discharge was 22 cfs in 1945 (Scott et al., 2002).

Figure 2-1 Head of the Levy Blue Spring Run.

Figure 2-2 Little Waccasassa River at the Alternate US 27 bridge.

South of the confluence with the Little Waccasassa, the Waccasassa River flows through the Devils Hammock (Figure 2-3), where a portion of the river discharge is diverted into Otter Creek (note the connection between the Waccasassa River and Otter Creek under the word Hammock in Figure 1-1). Further downstream, the Waccasassa River merges with the Wekiva River near Gulf Hammock (Figure 2-4). The river then discharges into Waccasassa Bay, approximately 20 miles downstream from the confluence with the Little Waccasassa River.

Figure 2-3 Waccasassa River in the Devils Hammock swamp.

Figure 2-4 Waccasassa River near the confluence with the Wekiva River southwest of Gulf Hammock.

Waccasassa Bay (Figures 2-5 and 2-6), which also receives discharge from Otter Creek and Ten Mile Creek (Figure 1-1), extends into the Gulf of Mexico in coastal Levy County between Cedar Key and the Withlacoochee River. This shallow embayment is an important estuary that supports sport and commercial fisheries as well as a diverse ecosystem. These ecosystems range from offshore oyster reefs to salt marshes in the near shore environments (U.S. Fish and Wildlife Service, 1990).

Figure 2-5 Waccasassa River near its mouth. Trees are growing on a small natural levee. Tree damage is from 2004 hurricanes and salinity increases due to sea level rise.

Figure 2-6 Salt marsh at the mouth of the Waccasassa River.

2.3 Climate of the Study Area

The climate of the Waccasassa River Basin can be described as subtropical. District-wide, the mean annual temperature is 68.6°F (NOAA, 2002). The maximum and minimum average monthly temperatures are 81.3°F (in July) and 54.2°F (January), respectively. Average annual rainfall in the basin varies spatially from about 55 inches in the upper, inland portions of the basin to over 60 inches near the Gulf coast (Figure 2-7; NOAA, 2002). This precipitation gradient is largely controlled by proximity to the Gulf of Mexico (NOAA, 1972).

Year-to-year rainfall variability is much greater than these average annual spatial differences. In the area covered by the NOAA North Florida Climatic Division, annual (calendar year) rainfall has varied from a low of 35.5 inches (1955) to a high of 77.9 inches (1964). Figure 2-8 shows the long-term (104 year) rainfall conditions for the north Florida region. The data were smoothed with a LOWESS-type smoothing algorithm as implemented in Table Curve 2D (AISN Software, 2000). As shown, the smoothed curve suggests that a drier period existed in the first half of the 20^{th} Century, with wetter conditions subsequently prevailing through the 1990's.

Figure 2-7 shows the typical monthly rainfall pattern at three locations in the District. The precipitation gage at Usher Tower is located within the Waccasassa basin and its rainfall data are considered representative of the basin as a whole. A strong seasonal pattern is observed in the vicinity of the Waccasassa River Basin where a pronounced wet season occurs in the summer months (June through September). In this area, summer rainfall is associated with localized, convectional thunderstorms or periodic tropical weather systems (hurricanes, tropical storms). This pattern weakens in the middle and northern parts of the District (compare Usher Tower data to the Jasper and Tifton data, Figure 2-7).

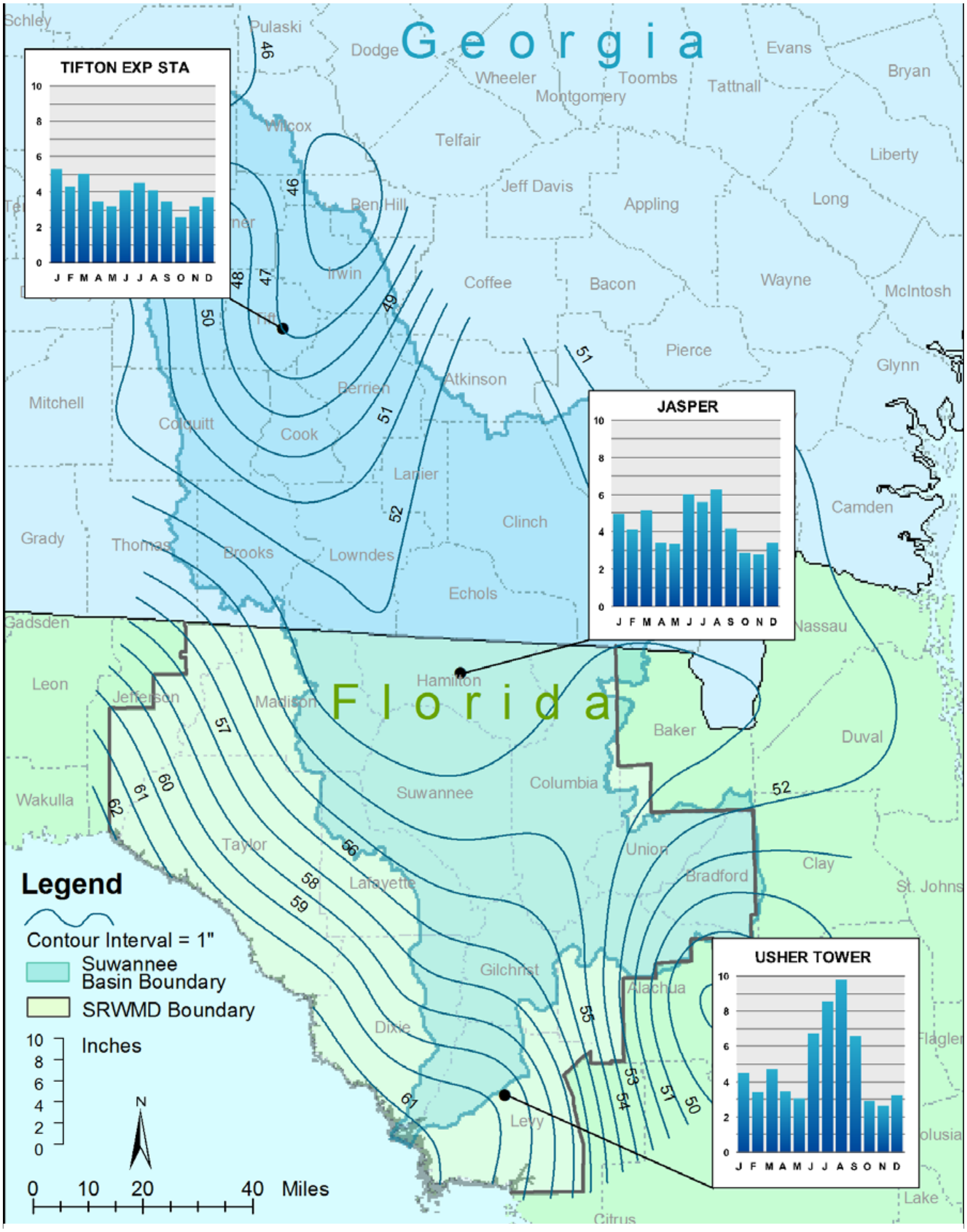

Figure 2-7 Average annual and monthly rainfall patterns in the Suwannee River and adjacent basins. Data: NOAA (2002). The Waccasassa Basin is located in the vicinity of Usher Tower on the figure.

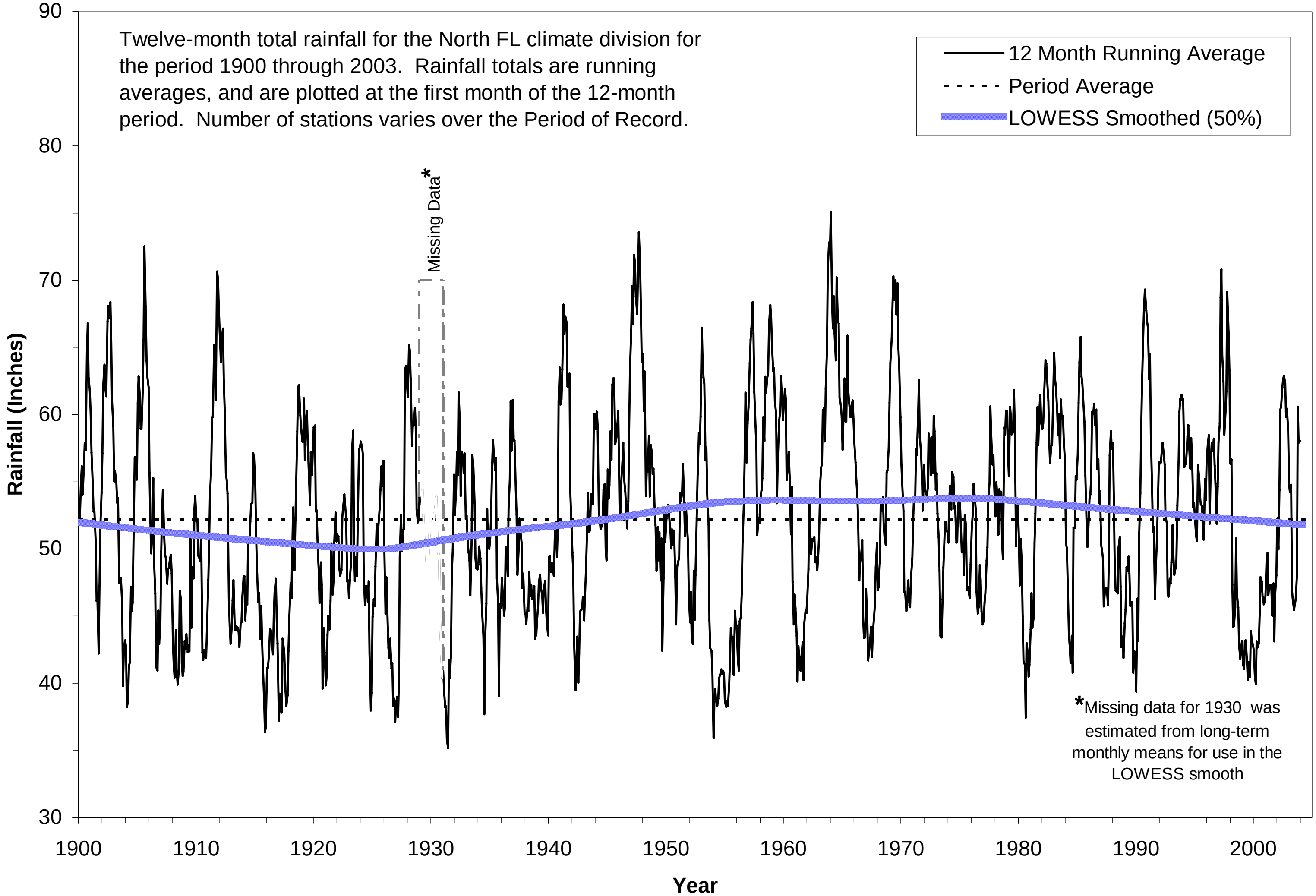

Figure 2-8 Twelve-month total rainfall for the North Florida climate division for the period 1900 to 2003. Rainfall totals are running averages and are plotted at the first month of the 12-month period. Data: NOAA (2005).

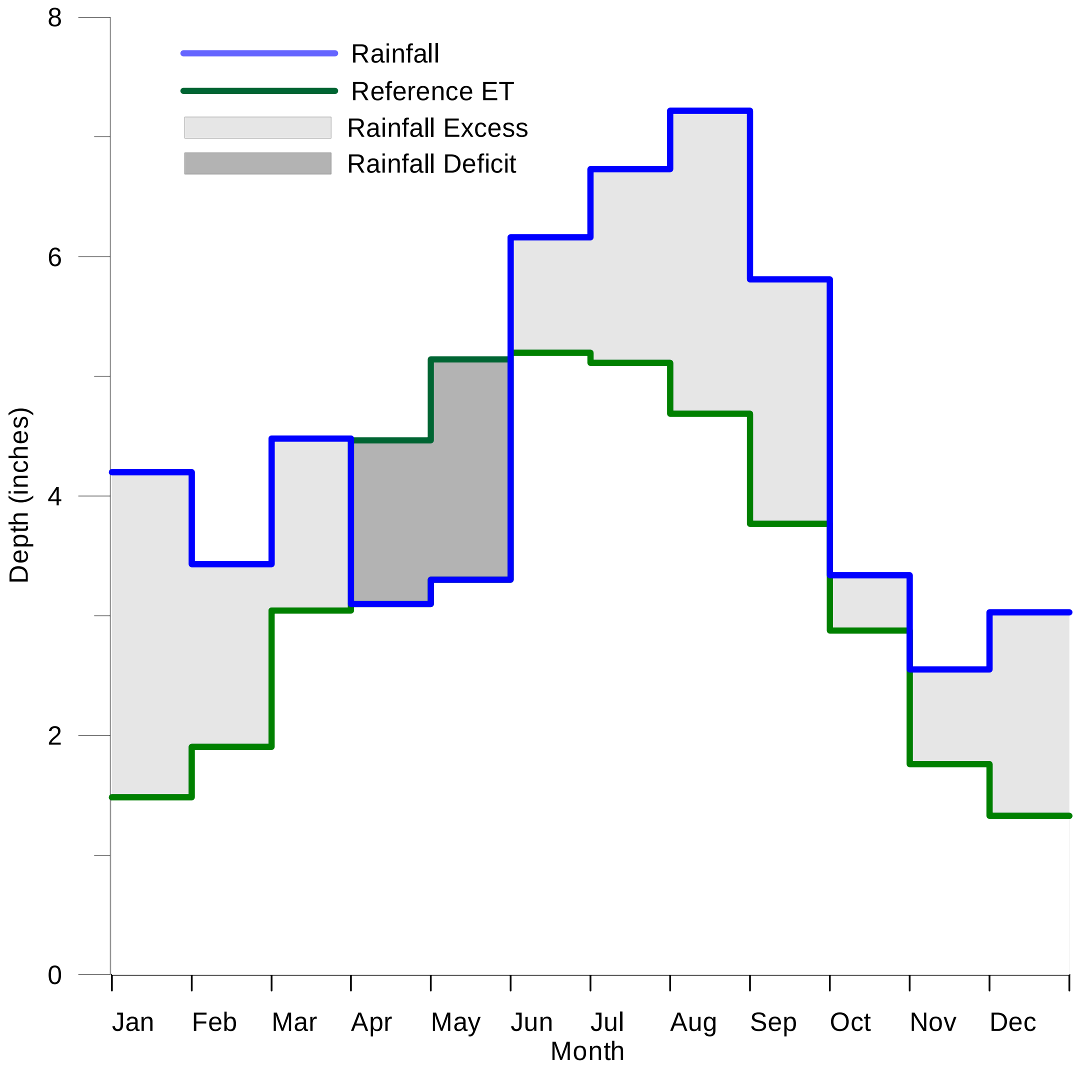

Figure 2-9 Mean monthly rainfall and reference evapotranspiration in the north Florida region. Data: NOAA (2002); Jacobs and Dukes (2004); Jacobs and Satti (2001).

Evapotranspiration (ET) rates in the region have been estimated with a variety of direct measurements and/or computational methods. The average annual ET pattern shown in Figure 2-3 is estimated from computed reference ET for Gainesville (Jacobs and Dukes, 2004) multiplied by monthly crop coefficients for pasture (Jacobs and Satti, 2001). Reference ET is the potential ET from a short, well-watered grass crop. The resulting mean annual ET is 40.8 inches, with the largest mean monthly value of 5.20 inches in June and a minimum of 1.3 inches in December. The monthly rainfall values in Figure 2-9 are the North Florida Climatic Division means (NOAA, 2002).

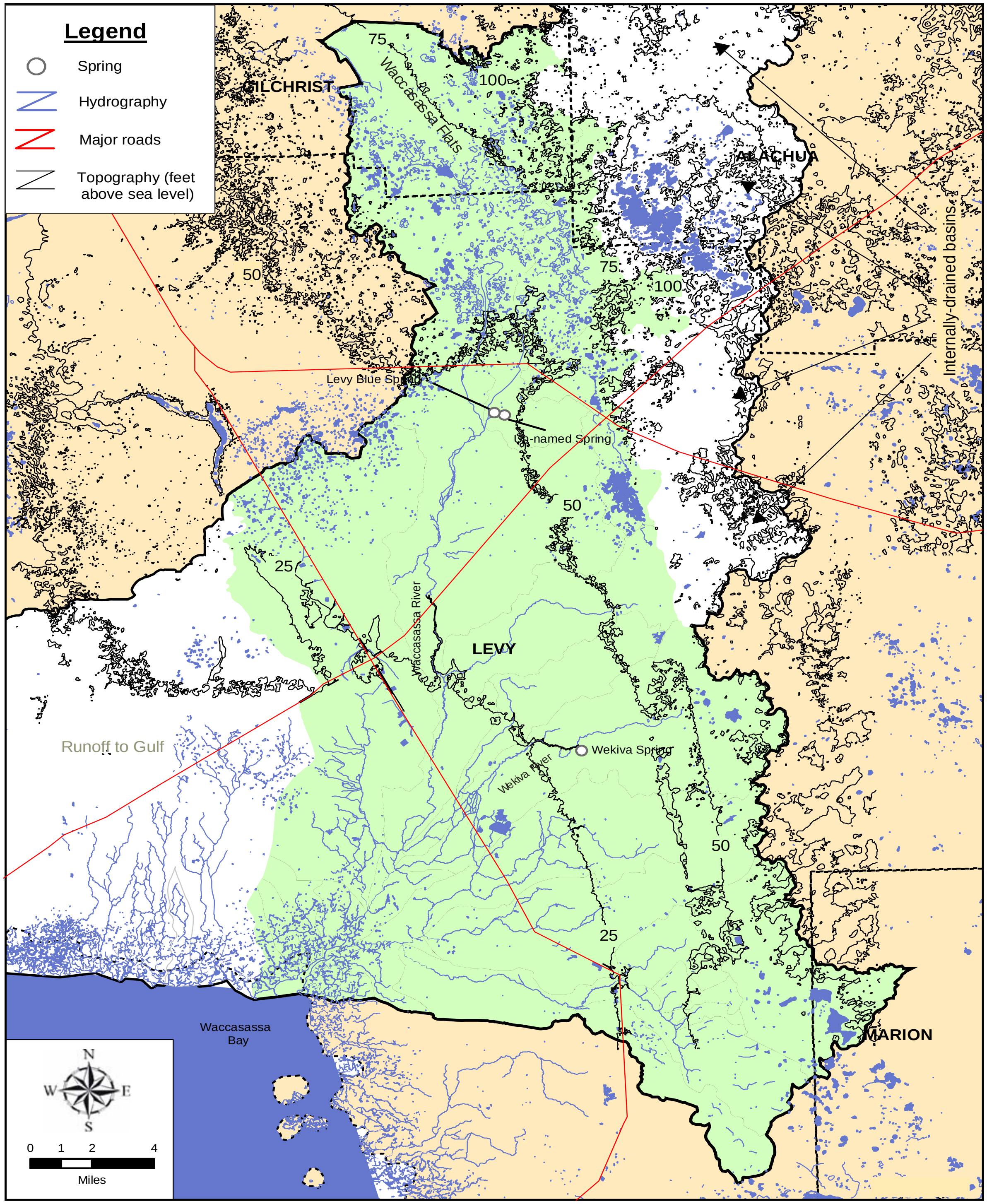

Figure 2-10 Elevations in the Waccasassa River Basin.

Figure 2-9 indicates potential months of net rainfall surplus and/or deficit. During the cooler winter months, a water surplus can exist that serves to recharge the ground-water system. During late spring, a rainfall deficit can occur. Utilization of soil moisture (Fernald and Purdum, 1998) and late frontal systems can offset this effect. In the summer, the situation reverses, with rainfall typically exceeding ET. However, for climate-affected activities, such as agriculture, the scattered nature of summer convective rainfall events combined with excessive- to well-drained soils often result in site conditions that require supplemental irrigation.

2.4 Topography, Physiography, and Drainage

Land-surface elevations in the Waccasassa River Basin range from sea level along the coast to heights in excess of 100 feet above msl in upland areas of Alachua and Gilchrist counties (Figure 2-10). However, the Waccasassa River generally lies at an elevation below 50 feet above msl. As a result, the river has a very low gradient, resulting in sluggish flow along much of its course.

The Waccasassa River Basin spans three major physiographic provinces (Figure 2-11), the Brooksville Ridge, the Gulf Coast Lowlands, and the Coastal Swamps (White, 1970). The Brooksville Ridge is an upland area (typically greater than 75 feet above msl) capped by relatively discontinuous, clay-rich sediments, resulting in local surface-water runoff. The Brooksville Ridge is characterized by an abundance of sinkholes and closed depressions (Figure 2-12) favoring the formation of large internally drained basins and greatly increasing the relative amount of recharge to the Floridan Aquifer.

The Gulf Coast Lowlands is an area of subdued topography (typically between 25 and 75 feet above msl), underlain by a thin veneer of sand over the karstic limestone of the Floridan Aquifer. It is a mature karst plain characterized by low recharge and localized areas of discharge, such as at springs and along the channels of large streams. Recharge is limited because of high water-table conditions and locally upward ground-water gradients. Sinkholes in the Coastal Lowlands are typically small in area (Figure 2-12), but they are numerous (Upchurch, 2002).

The Coastal Swamps found immediately adjacent to the Gulf of Mexico are characterized by low, swampy areas and drowned karst topography (White, 1970). In this region, drainage is mainly toward the Gulf through numerous tidal creeks and tidal-flat areas. The Coastal Swamps are a major discharge zone for the Floridan Aquifer in the Waccasassa River Basin.

2.5 Geology and Hydrogeology

This section describes the geologic and groundwater systems of the District and the Waccasassa River Basin.

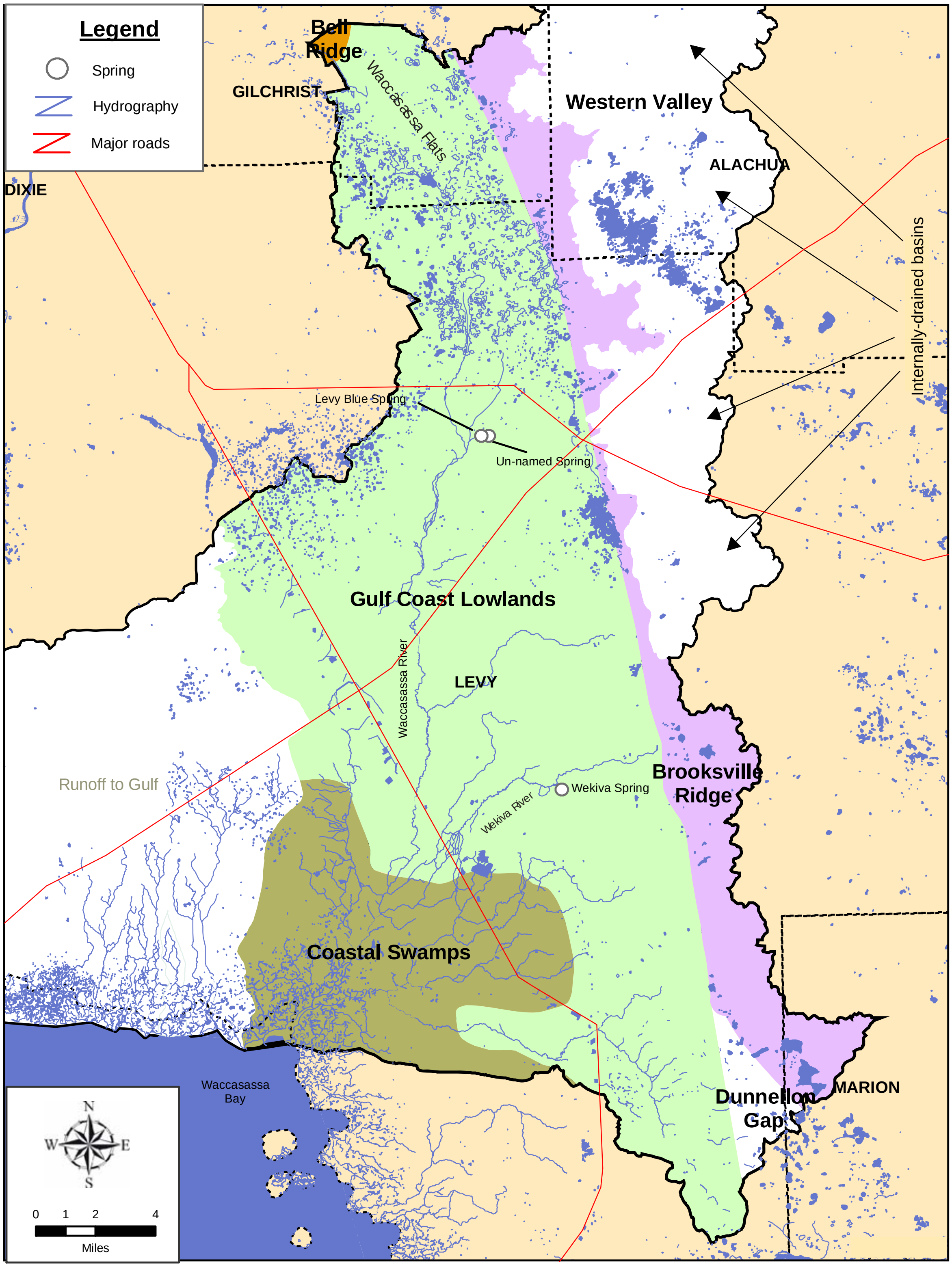

Figure 2-11 Physiographic provinces of the Waccasassa River Basin.

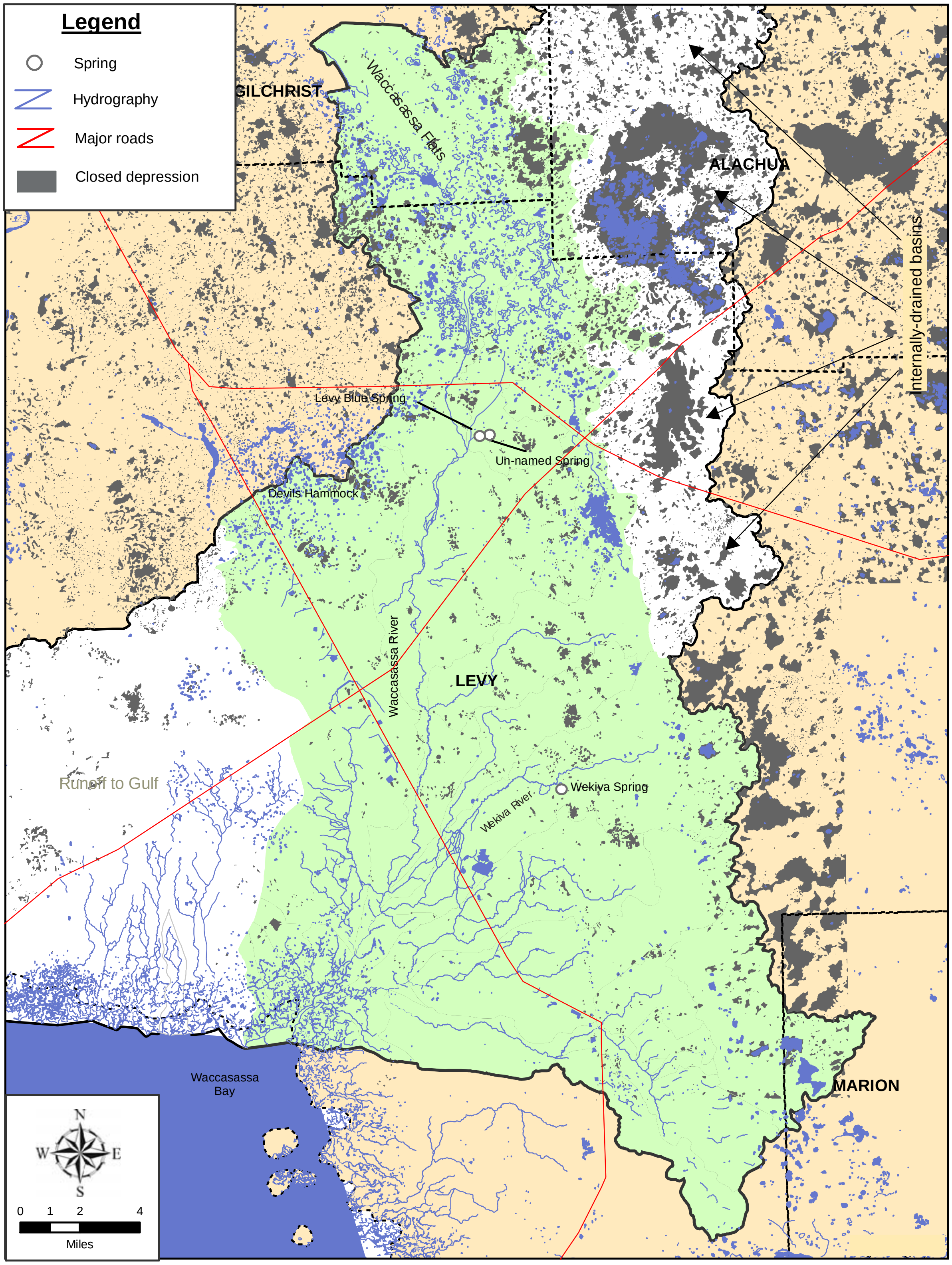

Figure 2-12 Distribution of closed depressions, which are interpreted as representing sinkhole-related landforms in the study area.

2.5.1 Stratigraphy

The Florida Platform is composed of carbonate rock (limestone and/or dolostone), primarily Tertiary in age, which is as much as 5,000 feet thick within the District. The Floridan Aquifer, which ranges from about 600 feet to 1,700 feet in thickness, is found within these strata and in similar strata in Georgia, the Carolinas, and portions of Alabama (Miller, 1982).

The upper surface of the Tertiary limestone ranges from sea level to +90 feet above msl throughout most of the District (Figure 2-13). However, in the northeastern corner of the District, the limestone dips to the northeast with a slope of about 20 feet per mile, reaching a depth of about 300 feet below msl in the eastern corner of the District (Figure 2-13). Within the Waccasassa River Basin, the top of the limestone ranges from about -10 to +30 feet above msl (Figure 2-13).

Table 2-1 presents the lithostratigraphic (geologic formation) and hydrostratigraphic (aquifer system) nomenclature used to characterize the shallow geologic and hydrogeologic units in the District.

Table 2-1 Generalized lithostratigraphic column and aquifer systems in the Waccasassa River Basin.

LITHOSTRATIGRAPHIC (ROCK) NOMENCLATURE			AQUIFER SYSTEM
SYSTEM	SERIES	FORMATION	
Quaternary	Holocene/Pleistocene	Undifferentiated Sands	Surficial
Tertiary	Pliocene	Undifferentiated Sands	Surficial
Tertiary	Miocene	Hawthorn Group	Intermediate
Tertiary	Oligocene	Suwannee Limestone	Upper Floridan
Tertiary	Eocene	Ocala Limestone Avon Park Limestone Oldsmar Limestone	Upper Floridan
Tertiary	Paleocene	Cedar Keys Formation	Mid-Floridan Confining Unit

Figure 2-14 shows the distribution of these units at or near land surface within the Waccasassa River Basin. Throughout much of the Gulf Coast Lowland and the Coastal Swamp physiographic provinces, thick sequences of limestone are exposed at or very near (10-20 feet) the land surface. The thin veneer of sediment found in these provinces consists of Quaternary-age, unconsolidated to poorly indurated, siliciclastic deposits dominated by quartz sand. These sands are primarily marine terrace deposits.

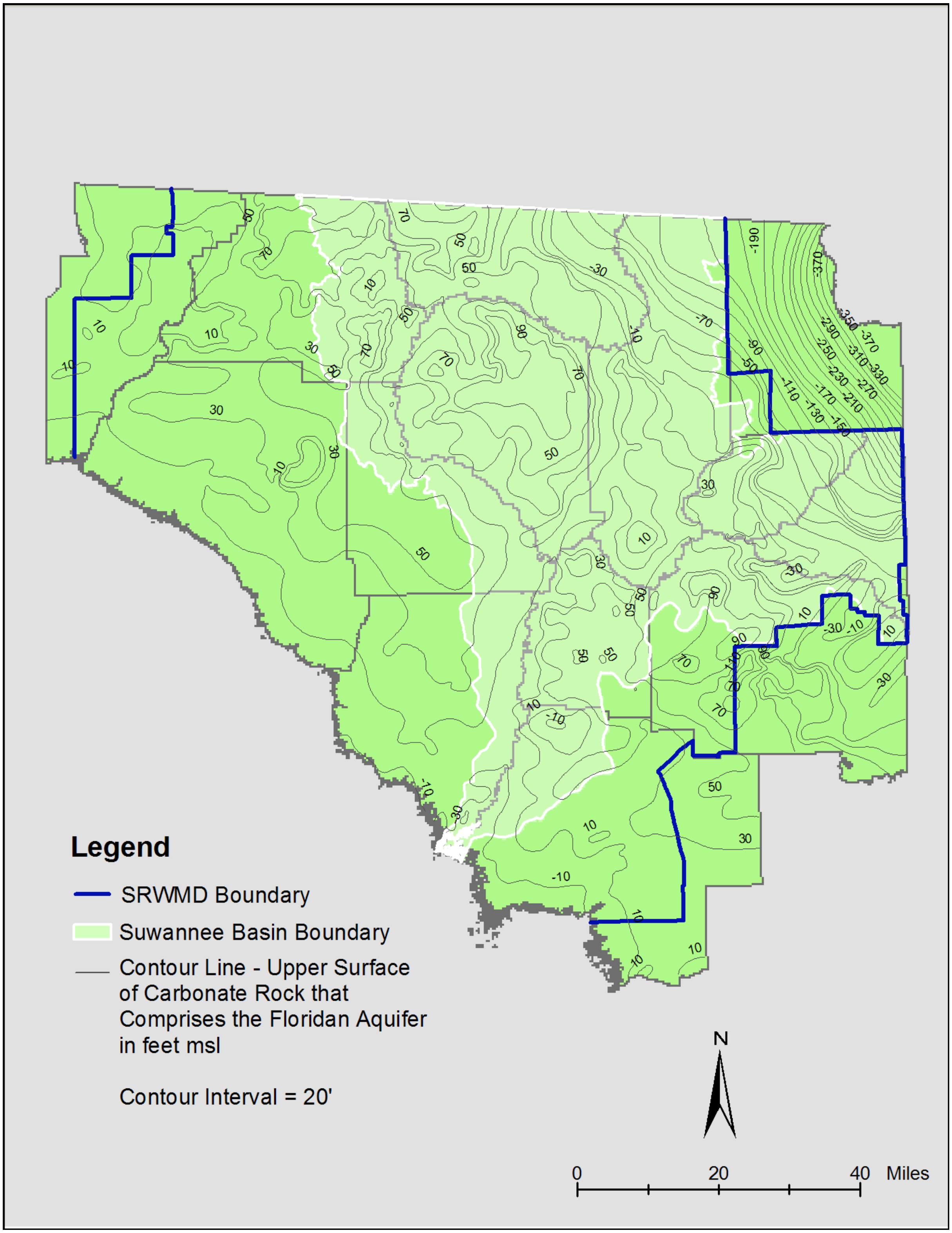

Figure 2-13 Elevation of the upper surface of the Tertiary limestone strata that constitute the Floridan Aquifer within the District. The Waccasassa Hydrologic Unit is included within those portions of the District southeast of the Suwannee Basin. Source: Allison et al. (1995).

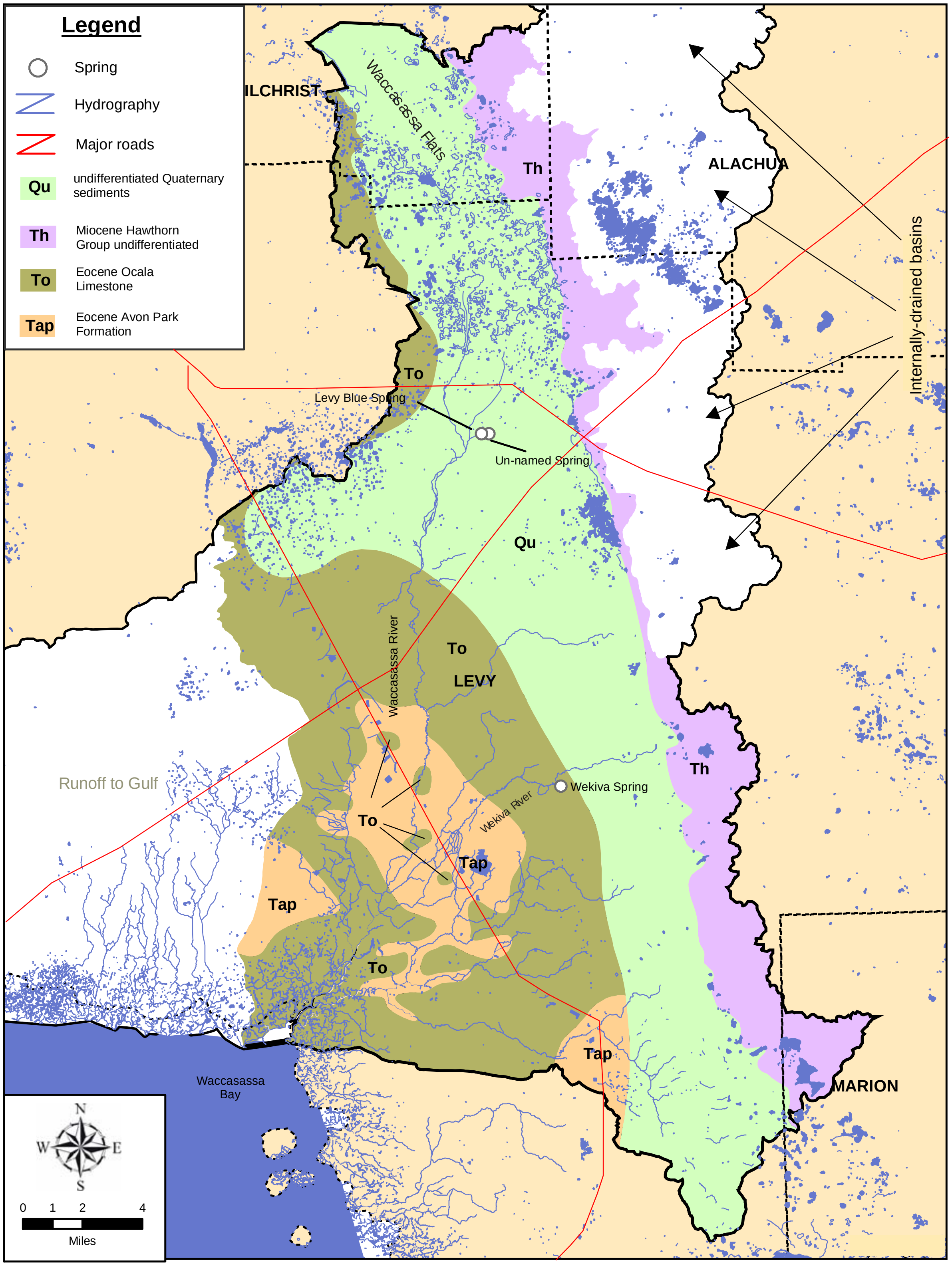

Figure 2-14 Geologic map of the Waccasassa River Basin. Source: Florida Geological Survey.

The Waccasassa Flats, where elevations average about 60 feet above msl, are underlain by clay-rich, Quaternary and Pliocene to Miocene sediments that occupy a north-south trending trough in the limestone surface 75+ feet deep (Col et al., 1997). Vernon (1951) postulated that this trough was a remnant stream valley, possibly of the ancestral Suwannee River. Puri et al. (1967) argued that it is of marine origin. Whatever the origin, the sediments underlying the Flats have relatively low permeability, so surfacewater stands in many areas and several small streams originate within the Flats.

Along the Brooksville Ridge (Figure 2-11), interbedded phosphatic sands, clays, and dolostones of the Miocene Hawthorn Group (Scott, 1988) are present beneath Plio-Pleistocene terrace sediments (Figure 2-14). Due to its clayey composition, the relative permeability of the Hawthorn Group is generally low and tends to form a local confining unit above the Floridan Aquifer and below the Surficial Aquifer System.

The Hawthorn Group overlies the carbonate units of the Floridan Aquifer (Scott et al., 2001). These formations include (from top, or youngest, to bottom, or oldest) the Oligocene Suwannee Limestone, Eocene Ocala, Avon Park, and Oldsmar formations, and the Paleocene Cedar Keys Formation (Table 2-1; Giller, 1997). These strata comprise the Upper Floridan Aquifer system and, where present, the Mid-Floridan Confining Unit. The Ocala Limestone is the primary source of groundwater in the majority of the Basin. .

The Ocala Limestone crops out along the middle and lower reaches of the Waccasassa River (Figure 2-14). Based on well cuttings, Crane (1986) described the Ocala Limestone in the study area as consisting of several lithologies of marine origin. The deepest of these lithologies is a medium to well-indurated calcarenite composed almost entirely of Miliolid foraminifera. Above this unit lies a medium to well-indurated calcarenite composed of the foraminifera *Operculinoides* sp. and Miliolids. Capping these two lower lithologies is a poorly to moderately indurated calcarenite composed of the foraminifera *Lepidocyclina* sp. The upper surface of the Ocala Limestone is highly variable and karstic (Crane, 1986).

The Avon Park Formation is the oldest formation that crops out in Florida, with an upper surface that is also highly variable and karstic (Crane, 1986). In the study area, the early Eocene age Avon Park Formation consists of moderate to well-indurated, sugary dolostone, and moderately to well-indurated calcilutite, calcarenite and calcirudite. Thin seams of peat are often associated with the more dolomitized sections of the Avon Park Formation. In deeper, more calcitic sections of the Avon Park, Miliolids and foraminifers, especially *Dictyoconus americanus,* are often present (Crane, 1986). Gypsum is also present in small amounts in the Avon Park Formation, though it typically occurs several hundred feet below sea level in the study area (Crane, 1986).

2.5.1 Aquifer Systems

The uppermost aquifer within the District is the Surficial Aquifer System (Table 2-1). The Surficial Aquifer occurs within the undifferentiated, Plio-Pleistocene, marine-terrace sands. This aquifer is only present locally in the northern and eastern parts of the study area where the underlying Hawthorn Group provides an effective aquitard, which minimizes recharge to the underlying aquifer. The Surficial Aquifer may be locally utilized for domestic well water and low volume irrigation. However, because of dissolved organics, color, odor, and iron problems, water quality is generally poor.

The Intermediate Aquifer System (Table 2-1), where present, is composed of siliciclastic and carbonate sediments of the Hawthorn Group. These strata primarily act as a local, leaky aquitard within the study area, but thin layers of gravel, sand, and carbonate rock may form localized aquifers that are capable of producing water to small-yield wells in the Brooksville Ridge.

The primary aquifer for water use within the study area, however, is the Floridan Aquifer System. The Floridan Aquifer System is generally divided into the Upper Floridan and Lower Floridan Aquifers. The Upper and Lower Floridan Aquifers are separated by the Mid-Floridan Confining Unit (Table 2-1). Figure 2-15 depicts the regional potentiometric surface for the Upper Floridan Aquifer in the District in May 1976. These contour lines represent the elevations of the water table where the aquifer is unconfined. Where it is confined, they correspond to the elevation to which water would rise within a well open to this aquifer. Groundwater flows from high to low potential, and the flow direction is generally perpendicular to these potentiometric contours. The average flow rate through the aquifer is estimated to be a few feet per day or less.

A potentiometric surface of the Floridan Aquifer System in the Waccasassa River Basin is shown in Figure 2-16. The potentiometric high within the Waccasassa Flats represents a region of relatively low permeability in the Floridan Aquifer combined with poorly-drained surficial soils and rejected recharge. The increased spacing between the isopotential lines in the southern and western portion of the basin suggests a well-developed karst terrain resulting in higher hydraulic conductivity in the Upper Floridan Aquifer. Based on the potentiometric surface shown in Figure 2-16, ground-water flow in the Waccasassa watershed is generally toward the southwest. This direction is subparallel to the axis of the watershed. Finally, a large and broad re-entrant in the potentiometric surface of the Floridan Aquifer, from the area of Wekiva Spring to the Gulf of Mexico, indicates regional ground-water discharge along the lower reaches of the Waccasassa River.

In the vicinity of the Gulf of Mexico, fresh water within the Floridan Aquifer overlies deeper, more saline water related to the Gulf of Mexico. The two water types are separated by a fresh-water/salt-water transition zone, a wedge-shaped ground-water zone characterized by upward movement and mixing of fresh water with saline water. The position of the transition has been roughly delineated by sodium and chloride data along the Gulf of Mexico (Upchurch, 1990), and it has been defined by geophysics within a 12.4-mile (20-kilometer) radius around the mouth of the Suwannee River (Countryman and Stewart, 1997). Shallow aquifer water within about 5 miles of the Gulf Coast tends to have relatively higher concentrations of sodium, chloride and potassium; however, the chloride concentration does not exceed 25 mg/L (Copeland, 1987). Well depths in the larger coastal communities range from 85 feet to 170 feet without a significant increase in sodium, chloride or sulfate concentrations.

Recharge to the Floridan Aquifer System is directly related to the confinement of the aquifer system. The highest recharge rates occur where the Floridan is unconfined or poorly confined, as in those areas where the Floridan Aquifer is at or near land surface. The degree of confinement of the Upper Floridan Aquifer is a critical factor in aquifer dynamics and management. The District has compiled a hydrogeologic classification based on the degree of confinement of the Floridan Aquifer (Figure 2-17) by combining and evaluating the physiography, geology, and hydrogeology (SRWMD, 1982). The classes of confinement are as follows.

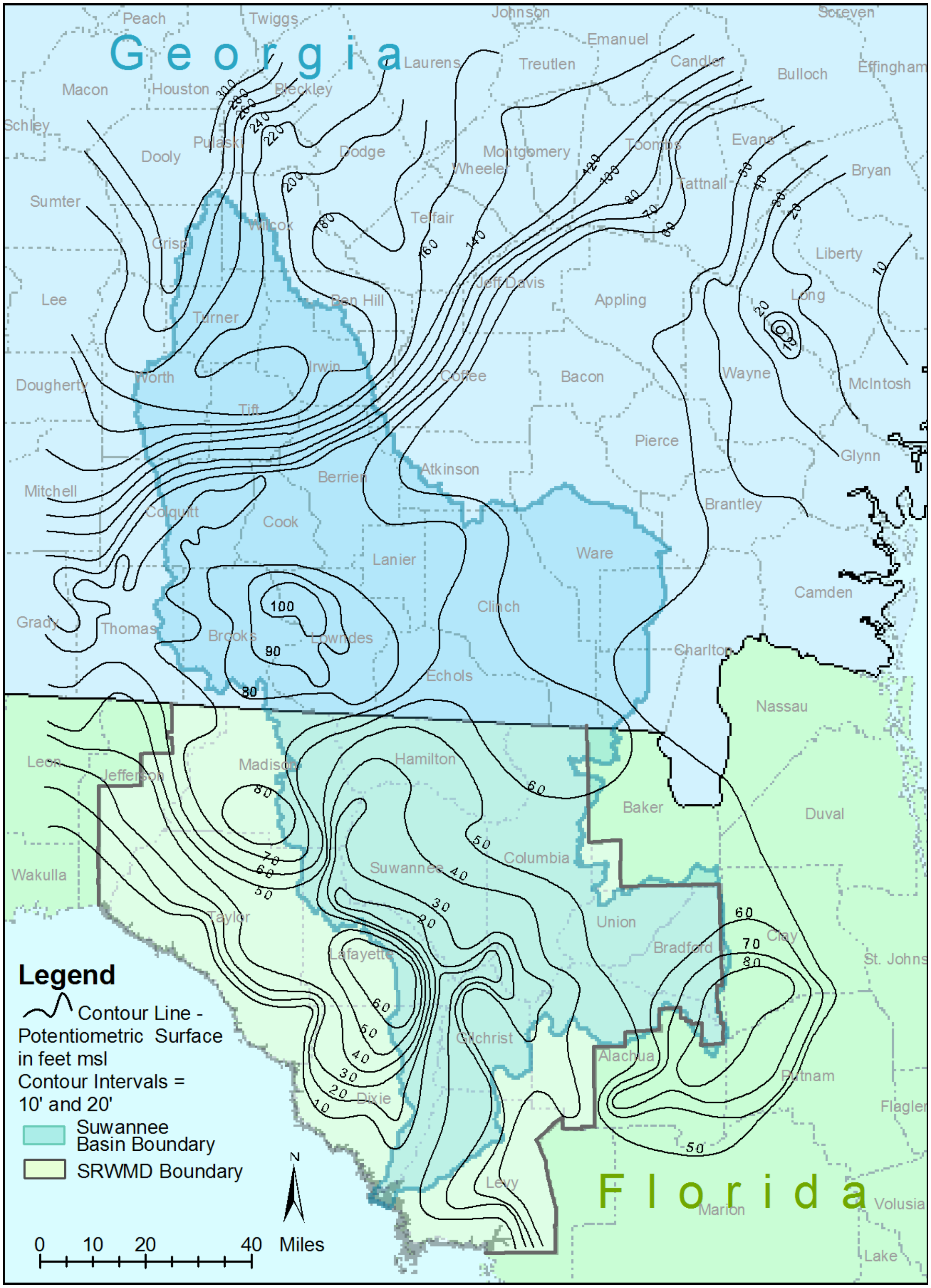

Figure 2-15 Potentiometric surface of the Floridan Aquifer in May 1976. The Waccasassa Hydrologic Unit lies within the areas shown in gray to the southeast of the Suwannee Basin. Adapted from Laughlin (1976); Rosenau and Meadows (1977); Fisk and Rosenau (1977).

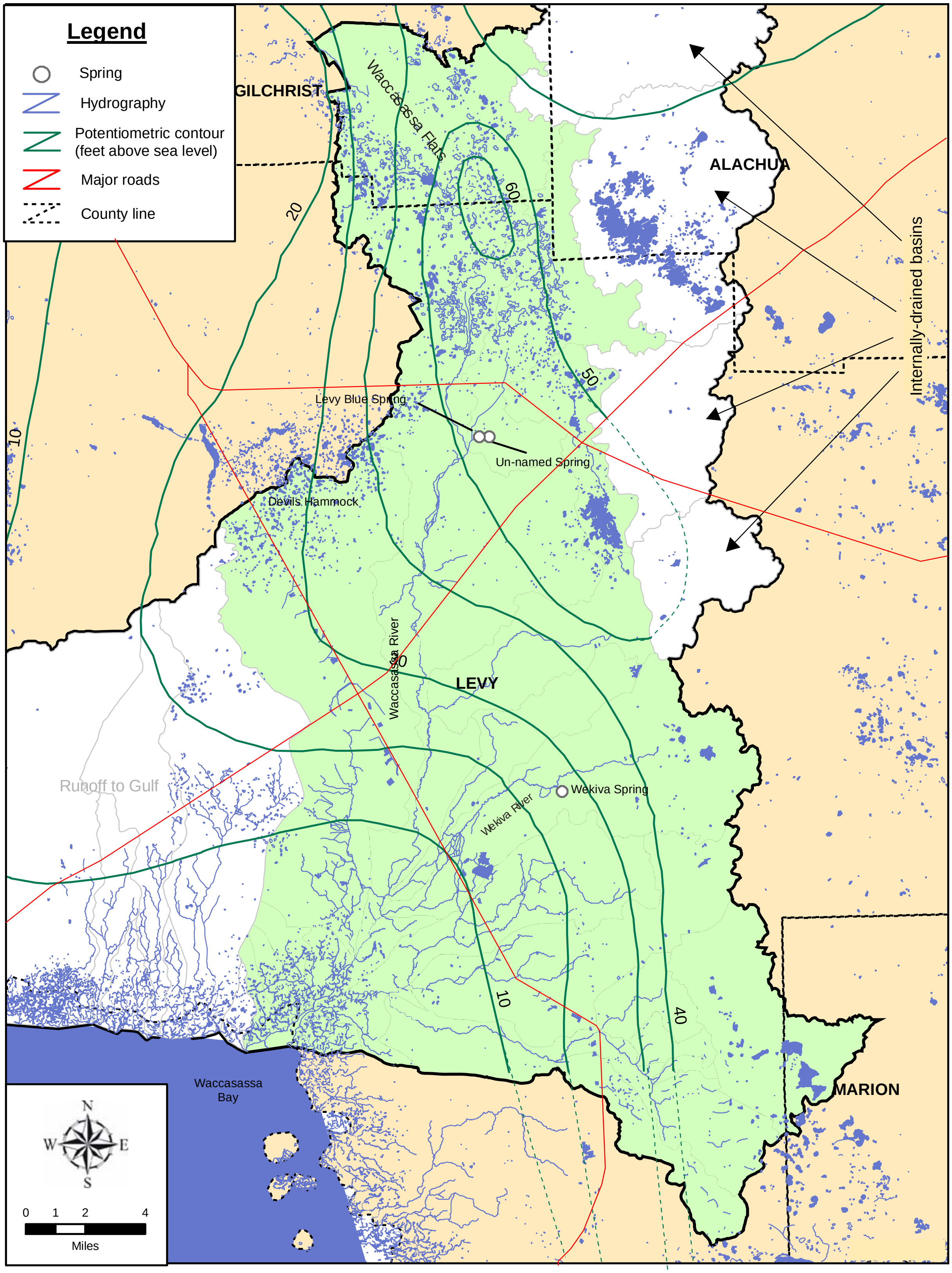

Figure 2-16 Potentiometric surface of the Floridan Aquifer in the Waccasassa River Basin in 1995.

Class 1 – Unconfined. Class I conditions exist where the Floridan is unconfined, is the only aquifer present, and the carbonate rock is at or near land surface. Where the limestone is not exposed, the Floridan is usually covered by porous sand. The limestone is porous and permeable, exhibiting a high degree of secondary porosity that has been enhanced by a fluctuating water table. Due to the porous nature of the rock and sand, rainwater recharges the aquifer directly. Recharge rates in this region range from 16 to 31 inches annually (Grubbs, 1998). Surfacewater features usually represent exposures of the water table in the unconfined Floridan Aquifer.

Class II - Semi-confined. Class II conditions exist where the Floridan Aquifer is semi-confined on top by discontinuous, leaky, clay beds. The Class II area in Gilchrist, Alachua and Levy counties coincides with the Waccasassa Flats and the Class II area in Madison, Taylor, Dixie and Lafayette counties coincides with the San Pedro Bay/Mallory Swamp region. Because of reduced recharge, there are streams that drain the Waccasassa Flats and the San Pedro Bay, and there are lakes on the edges of these features. The Class II area that extends southeast from Suwannee County to Columbia County is the transition zone that parallels the Cody Scarp. This area is characterized by sinking streams, sinkhole lakes that periodically drain into the Floridan, and numerous steep-sided sinkholes. Recharge rates to the Floridan are variable (Grubbs, 1998) and highly focused in location in this region.

Class III – Confined. The Class III area is characterized by deeper and confined portions of the Floridan Aquifer. Confinement is a result of at least 80 feet of Hawthorn Group clay overlying the Floridan. Recharge rates to the Floridan in this region average 12 inches or less annually (Grubbs, 1998). Confinement creates artesian conditions, and water levels in wells that penetrate these aquifers usually rise to within 15 feet of land surface. There are no Class III areas within the Waccasassa River Basin (Figure 2-17).

The Surficial Aquifer locally overlies the Floridan in the Class II and most of the Class III areas (Figure 2-17). The water table is a subdued replica of the topography and is at, or near, land surface. It coincides with surfacewater levels observed in the swamps, lakes, and ponds. Streams in these areas drain the Surficial Aquifer in addition to removing surface run-off. The Surficial Aquifer is recharged directly by rainfall, and water level fluctuations are directly related to the amount of rainfall.

Figure 2-18 shows the estimated recharge potential of the Floridan Aquifer in the Waccasassa watershed (SRWMD, 2001). Recharge is high in the area where the potentiometric surface is high and karst is well developed under the Brooksville Ridge. Discharge is dominant near the coast, where the fresh-water/salt-water transition zone forces upward flow.

Recharge may also be high in areas where the confining layers are breached by karst features, such as sinkholes in the Brooksville Ridge (Figures 2-11 and 2-12). Other factors affecting recharge rates include the development of surface-water drainage, variations in water-level gradients between surfacewater, the Surficial Aquifer and the Floridan Aquifer, and aquifer permeability. Low recharge rates occur where confining materials overlying the aquifer retard downward vertical movement of water, or where an upward gradient exists between the Floridan and Surficial Aquifers.

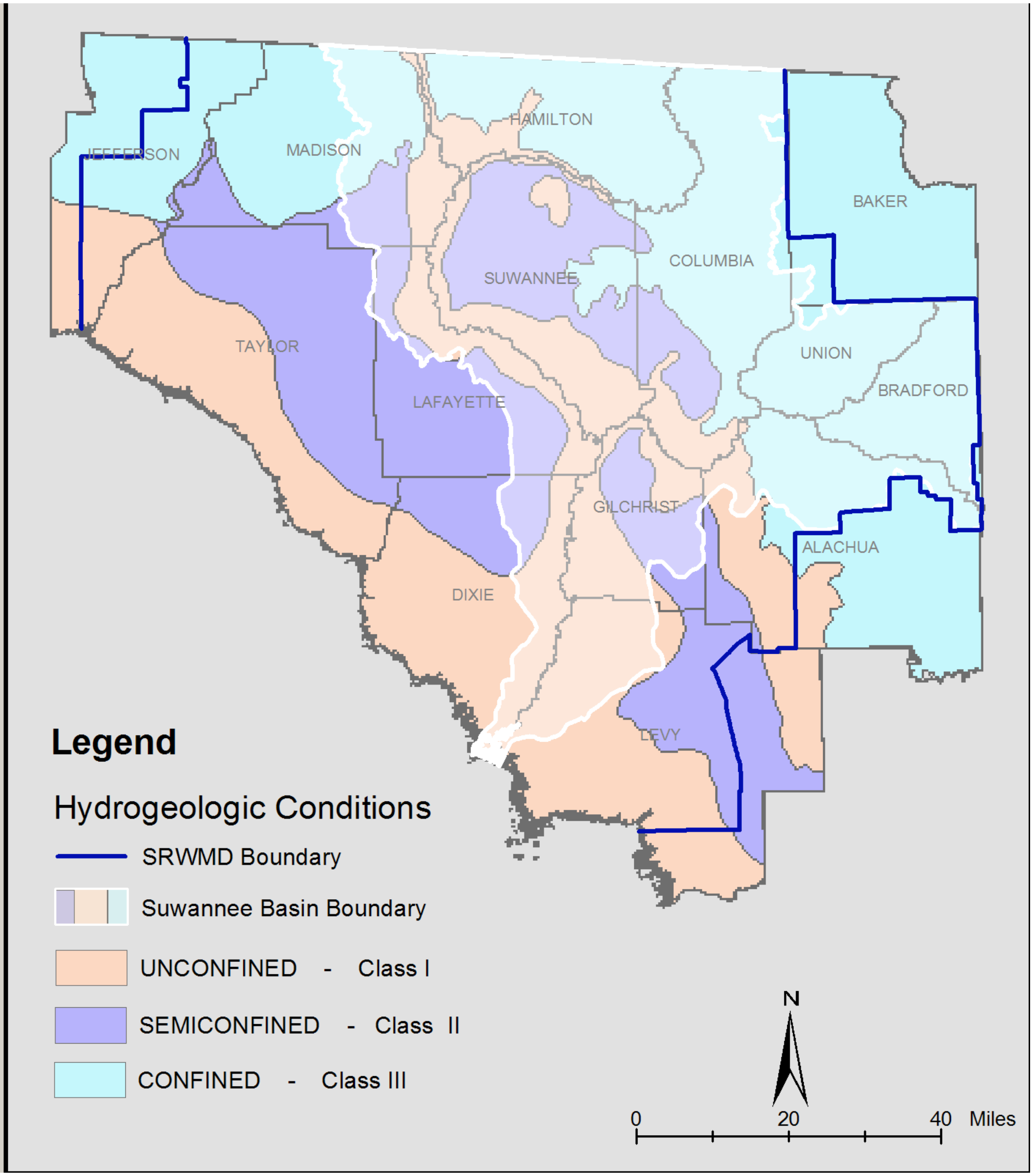

Figure 2-17 Confinement conditions of the Floridan Aquifer in the region. The Waccasassa Hydrologic Unit lies within those areas of the District southeast of the Suwannee Basin. Adapted from SRWMD (1982).

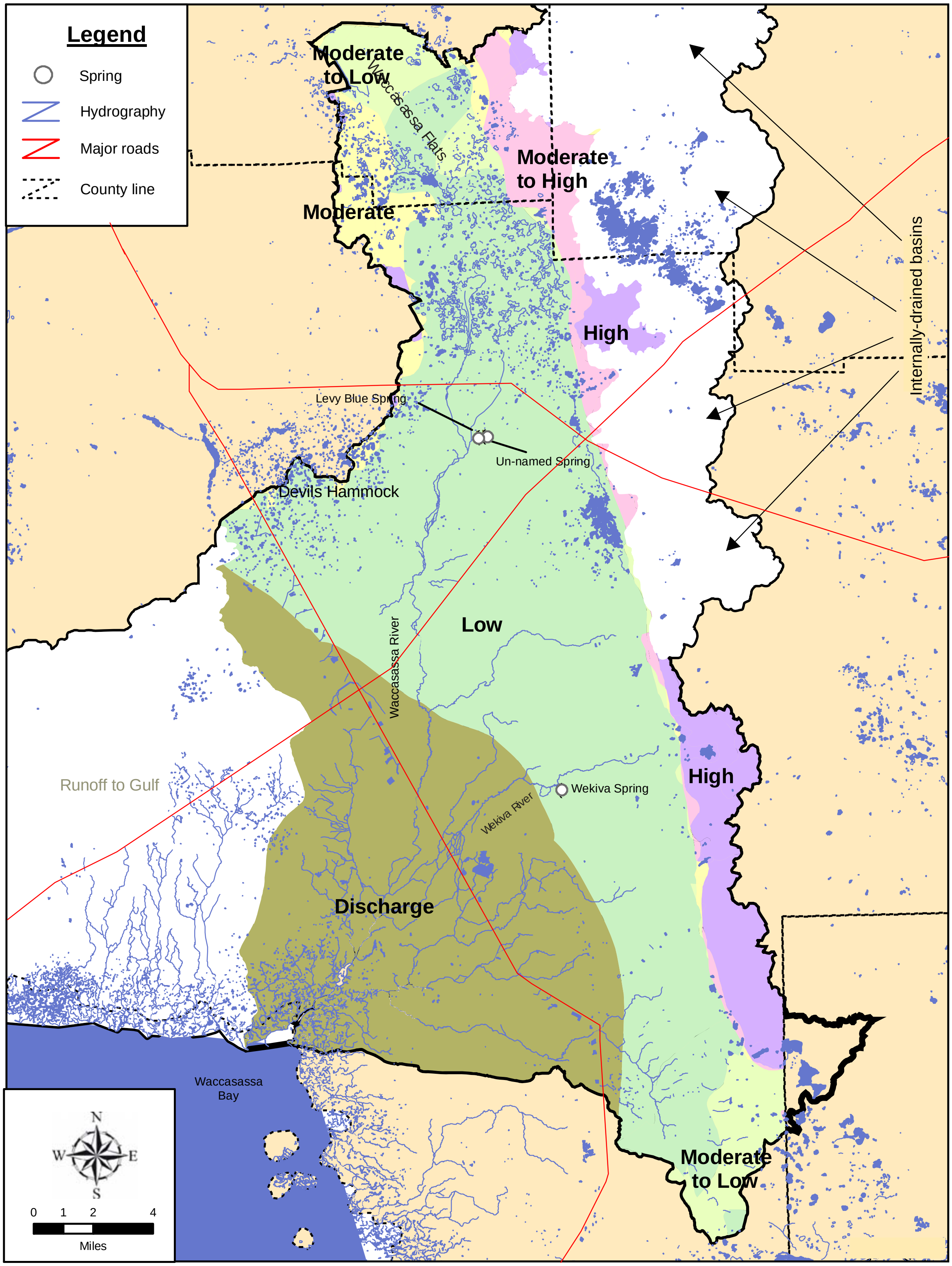

Figure 2-18 Estimated Floridan Aquifer System recharge potential in the Waccasassa River Basin. Data from the District.

2.5.2 Karst Hydrology

Karst processes play a dominant role in the occurrence and movement of surface and groundwater within the Waccasassa River Basin. The Brooksville Ridge (Figure 2-11), for example, is an area of intensive karst development, characterized by numerous sinkholes, lack of surface drainage, and undulating topography (Figures 2-10 and 2-12). In karst areas, the dissolution of limestone has created and enlarged cavities along fractures in the limestone, which eventually reach the land surface and form sinkholes. Sinkholes capture surface-water run-off and funnel it underground, which promotes further dissolution of limestone. This leads to progressive integration of voids beneath the surface over time and allows greater amounts of water to be transported through the ground-water system more rapidly.

Dissolution is most active at or immediately below the water table, typically within the zone of water-table fluctuation. In this zone carbonic acid contained in atmospheric precipitation and generated by reaction with soil carbon dioxide reacts with limestone and dolostone (Carroll, 1970). Because the altitude of the water table has shifted in response to changes in sea level over the last 30 million years, many vertical and lateral paths have developed in the underlying carbonate strata in the study area. Many of these paths or conduits lie below the present water table, which greatly facilitates ground-water flow.

Dye-trace studies in Columbia County north of the Waccasassa River Basin show that groundwater near Ichetucknee Springs may travel approximately one mile per day in active conduits in the Upper Floridan Aquifer (Karst Environmental Services, 1997). Similar velocities were recorded near Sulphur Springs in Hillsborough County (Stewart and Mills, 1984). Studies such as these clearly indicate that groundwater has the potential to flow rapidly and traverse great distances in a short amount of time in karst environments near major springs.

Because the flow in these karst conduits is rapid and direct, dispersion, dilution, and retardation of contaminants may be minimal. For example, when Lawrence and Upchurch (1976) sampled the Upper Floridan Aquifer in the vicinity of Lake City (Columbia County), they described a plume of surfacewater under Alligator Lake that extended to the southwest for several miles. Shortly after completion of the study, the lake drained and residents down gradient reported colored water, organic debris, and other indicators of lake water. Alligator Lake is part of the headwaters of the Ichetucknee Springs and the plume of surfacewater was migrating in a karst conduit system to the springs.

Recent studies by the USGS and SRWMD have demonstrated that much of the spring water discharging from springs in northern Florida has been in the Floridan Aquifer for 10-25 years (Katz et al., 1999). This estimate is based on age-dating techniques using chlorofluorocarbons (CFC's) derived from the use of aerosol propellants and refrigerants. These CFC compounds, released into the atmosphere over the last 50 years, have dissolved in precipitation that recharges groundwater (Katz and Hornsby, 1998). These studies show that, while a portion of the groundwater moves quickly through conduits in the Floridan Aquifer, much of the water percolates slowly through the soil and into the aquifer. Once the groundwater recharges the aquifer, it begins moving through the smaller pores and openings (or matrix) in the limestone before reaching an active conduit or spring vent. The slower movement of groundwater through the matrix of an aquifer, known as diffuse flow, allows most contaminants to break down before the water is more rapidly discharged through conduits in the aquifer. As a result, springs in the region are typically clear and free of most contaminants.

In the vicinity of large springs, rapid conduit flow and slower diffuse flow are, in fact, both very important aspects of overall groundwater flow characteristics. Older, more predominant groundwater from diffuse flow through the aquifer matrix mixes with younger groundwater traveling through active conduits near large springs. Two recent studies by the St. Johns River Water Management District and the Suwannee River Water Management District demonstrate and support this mixing model of groundwater at springs (Katz and Hornsby, 1998; Toth, 1999). Therefore, the mixing of groundwaters must not be overlooked when assessing the origin, health and history of spring waters in karst environments such as found in the Waccasassa River Basin.

2.6 Surfacewater Hydrology

2.6.1 Drainage Patterns

Surfacewater features are abundant throughout the Waccasassa River Basin (Figure 1-1). In the upper reaches of the watershed, surfacewater features (streams, lakes, swamps) are closely associated with the Waccasassa Flats. Further south, the Devils Hammock contains a mixture of forested wetlands and water-filled, closed depressions. In the lower reaches of the watershed, especially in the coastal swamps, numerous tidal creeks, swamps, and marshes abound. The abundance of streams and wetlands in the watershed reflects the relatively low substrate permeability, high water table, and tendency for groundwater to discharge to the surface throughout the Waccasassa watershed. The low surface gradient of the landscape causes much of the surfacewater in the region to pond on the surface, resulting in sluggish flow in the surfacewater systems.

2.6.2 Seasonal Flow Patterns

Heath and Conover (1981) recognized the existence of a “climatic river basin divide” in Florida that approximates the sub-basin boundaries of the lower Suwannee and Santa Fe Rivers (Figure 2-19). Streams north and west of the climatic divide exhibit high flows in the late winter/early spring, with late spring and fall low flows. Streams south of the climatic divide exhibit high flows in the late summer/fall, with spring low flows. Streams lying along the climatic divide tend to exhibit a mixture of both of these patterns (a “bimodal” pattern of floods in the spring and fall). More recently, Kelly (2004) reconfirmed these hydrologic patterns in streams in Florida, which he termed the “northern river” pattern (spring flooding), the “southern river” pattern (fall flooding), and the “bimodal” pattern (both spring and fall flooding). These temporal flow patterns are driven in part by climatic characteristics.

The Waccasassa River drainage basin falls in the transitional climatic area between the warm, temperate climate of the southeastern U.S. and the subtropical climate of the Florida peninsula (Figure 2-19). Higher, late winter/early spring rainfall and lower ET in the northern part of the basin (Section 2.3) drives the spring flooding, while high summer rainfall in combination with tropical weather events creates the southern river flooding pattern in peninsular Florida.

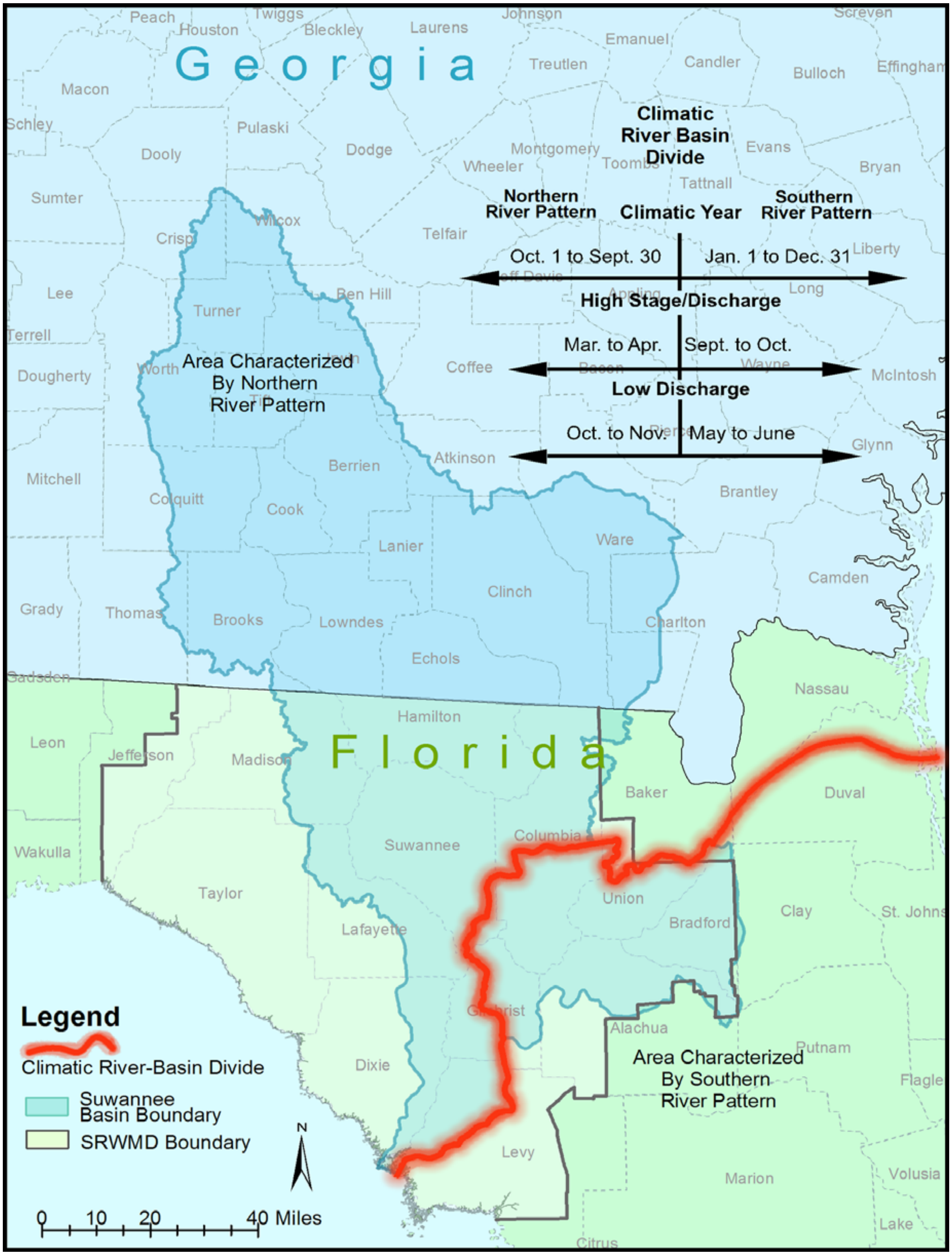

Figure 2-19 Climatic river-basin divide and climatic year designations of Heath and Conover (1981). River pattern data are from Kelly (2004). The Waccasassa Basin lies within the gray area southeast of the Suwannee River Basin.

2.7 Population and Water Use

The Waccasassa River Basin is sparsely populated. Bronson (Figure 1-1) is the largest center of population in the watershed, with approximately 3,700 residents (2000 census). The remaining area is rural and consists largely of agricultural and undeveloped land. Since 1960, the population of Levy County has increased 232 percent, from approximately 10,364 to 34,450 (U.S. Census Bureau, 2002). Despite this growth the County retains a decidedly rural character, with a population density of approximately 30 persons per square mile.

According to estimates by Marella (1999), groundwater was withdrawn from the Floridan Aquifer in Levy County at the rate of approximately 20.8 million gallons per day (mgd) in 1995. Agricultural withdrawals, rural self-supplied, and public water-supply systems accounted for approximately 73.1 percent (15.2 mgd), 17.8 percent (3.7 mgd) and 9.1 percent (1.9 mgd), respectively, of the total withdrawals in the County (Marella, 1999). Cumulatively, these withdrawals accounted for more than 99 percent of the water use in the County in 1995.

The District has estimated that total 2000 water use (WRA, 2004) in Levy County was 18.3 mgd. The estimated breakdown of use is shown in Table 2-2. By 2050, total water use is projected to be as much as 69 mgd (Table 2-2).

Table 2-2 Estimated current and projected water use in Levy County (WRA, 2004).

	Water Use (million gallons per day)						
Year	**Agriculture**	**Commercial, Industrial, Mining, Power**	**Domestic Self-Supply**	**Public Supply**	**Recreation**	**Yearly Total (mgd)**	**(cfs)**
2000	13.9	2.0	1.1	1.1	0.2	18.3	28.3
2050	55.1	6.3	3.7	3.4	0.5	69.0	106.76

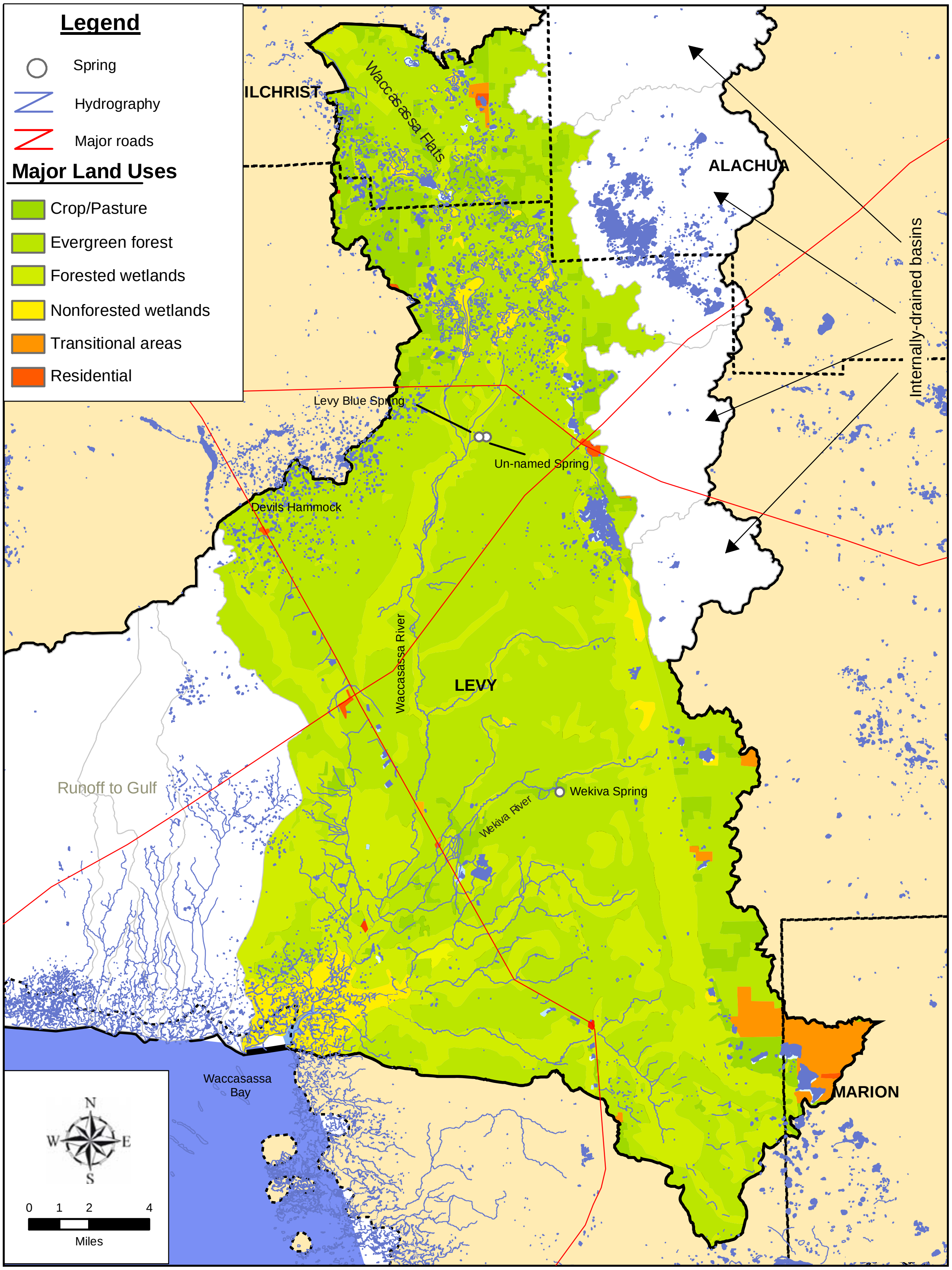

Figure 2-20 1996 land use in the Waccasassa River Basin.

2.8 Land Use

Land use in the Waccasassa River Basin (Figure 2-20) was identified using the 1996 USGS Arcview™ land-use coverage (Florida Geographic Data Library, 2004). Much of the watershed is covered by evergreen forest land and forested wetlands. Portions of the upper watershed are covered by crop and pastureland, while the coastal zone contains an abundance of non-forested wetlands. Less than one percent of the watershed is comprised of residential, commercial, and other urban land uses.

The land use coverage, specifically as it relates to forested and non-forested wetlands, will be revisited and described in more detail in section 4.

2.9 Habitats of the Waccasassa River

As stated previously, the Waccasassa River is a scenic and relatively undeveloped river. The headwaters originate in a broad complex of swamps and flatwoods of the Waccasassa Flats region. The river begins to flow through an expanse of bottomland hardwood swamp, and then through a complex of mixed wetland forests and pine plantations. The lower reach of the river is tidally influenced and characterized by the presence of tidally influenced wetland communities, including hydric hammock, tidal swamp and extensive tidal marshes (Figures 2-21, 2-22).

Figure 2-21 Swamp habitat along the Waccasassa River.

2.9.1 Riverine Habitats

2.9.1.2 Floodplain Wetlands

Figure 2-22 Coastal marsh and forest, dotted with cabbage palm in the Waccasassa Bay State Preserve.

All large river systems in the southeastern coastal plain, including the Waccasassa River, have extensive floodplain wetlands bordering the river channel (Wharton et al., 1976; Harris, 1984). These are primarily forested wetlands, or swamps. They are established and structured by hydrology; the periodic flooding and draining of the floodplain by variations in river flow (Leitman et al., 1983; Mitsch and Gosselink, 1986; Clewell, 1991). These floodplain wetlands are known to be an integral part of the river ecosystem, with important roles in nutrient, organic matter, and sediment dynamics, fish and wildlife habitat, and floodwater storage (Wharton et al., 1982; Mitsch and Gosselink, 1986; Schlosser, 1991; Kleiss et al., 1989; Light et al., 1998). Some of the organic production in floodplain wetlands is transported to the adjacent river and downstream to the estuary, and used in aquatic food webs (Mattraw and Elder, 1984). Hynes (1975) first elucidated the need to consider this important "lateral connectivity" in understanding and managing stream ecosystems, and subsequent conceptual paradigms in stream ecology have incorporated the importance of river-floodplain linkages (Ward, 1989; Schlosser, 1991).

Noss et al. (1995) designated riparian forests nationwide (including floodplain wetlands) as "threatened ecosystems", meaning they experienced a 70-84% decline in the occurrence of high quality, intact examples. In the southeastern U.S., the acreage of intact bottomland hardwood wetlands has declined by 78% since pre-European settlement times (Harris, 1984).

Bottomland Hardwood Swamp

Bottomland hardwood swamps occupy broad floodplains associated with rivers along the coastal plain. These forests and their faunal communities have been described as "fluctuating water level ecosystems" which attempts to characterize the natural hydrologic regime of alternating wet and dry periods on an annual basis (Wharton et al., 1982; Odum, 1969). Bottomland hardwoods often occupy transitional areas between permanent aquatic habitat and terrestrial uplands (Wharton et al., 1982). These wetlands include a diverse assortment of hydric hardwoods that generally occur on rich alluvial solids of silt and clay deposited along rivers. They are characterized by an overstory of water hickory, overcup oak, swamp chestnut oak, river birch, American sycamore, red maple, Florida elm, bald cypress, blue beech and swamp ash.

Mixed Wetland Forest

Mixed wetland forests represent communities that are dominated by neither hardwoods nor conifers, but rather include a mix of hardwoods, pine and/or cypress and represent a mixed hydric site or a transitional area between hardwoods and conifers.

2.9.1.3 Other Riverine Habitat

Springs and Spring Runs

Springs are important for several reasons including their contribution to riverine base flow and the presence of floral and faunal communities that occupy the springs and associated spring runs. Two important springs are located in the Waccasassa River system, Levy Blue Spring and Wekiva Spring, which are discussed in Section 2.10.

River Channel Riparian Snag Habitat

While quantitative data on the presence or location of snag habitat in the Waccasassa River is lacking, it is highly likely that snag habitat occurs in this system. As in the Lower Suwannee River system, the most ecologically important aquatic habitats in the river channel were associated with the riverbank zone (Bass and Cox, 1985; Dolloff, 1994). In particular, areas of submerged, large woody debris bordering river channels (Figure 4-5) have been shown to support high biological diversity and production (Dolloff, 1994; Maser and Sedell, 1994), especially in southeastern coastal plain streams (Benke et al., 1984; Benke et al., 1985). These have been referred to as "snag" habitats (Maser and Sedell, 1994; Benke et al., 1984). Much of the fish production in southeastern coastal plain streams may be associated with snag habitat (Benke et al., 1985; Smock and Gilinsky, 1992). Benke et al. (1985) showed that 82% of the diet of redbreast sunfish in the Ogeeche River was composed of snag-associated invertebrates.

2.9.2 Tidal River and Estuary

The Waccasassa Bay estuary is located at the mouth of the Waccasassa River (Figure 2-14). Mean tidal range in the estuary is reported as between 2.6 feet (Hine and Belknap, 1986) and 3.4 feet (McNulty et al., 1972; Tiner, 1993). Tides are mixed semi-diurnal, typically with two unequal high and two unequal low tides occurring each day (Section 3.1.2.3), separated in time by approximately 6.2 hours (Leadon, 1985). Low tide in the estuary occurs first near Cedar Key with the result that typical Suwannee fresh-water plumes flow southward along the coast (Leadon, 1985).

Depths in the Waccasassa Bay average 6.6 feet, with mean depths ranging from 2.9 to about 4.6 feet in the tidal portion of the river (Figure 2-14). Previous accounts report an average depth of less than 5 feet in the bay at mean low tide, with the exception of deeper channels that correspond to old stream courses (Abbott, 1998; Swindell, 1949).

This part of the coastline is considered low energy/microtidal (Hine et al., 1985) and has insufficient sediment to sustain beaches or dunes (Brunson et al., 1984). Tidal influence occurs for several miles inland along creeks that support tidal marsh vegetation indicative of tidal effects (Abbott, 1998).

2.9.2.1 Tidal Wetlands

Hydric Hammocks

Hydric hammocks are hardwood forests that grow on low, flat areas with poorly drained soils or in areas with a high water table. Hydric hammocks are still-water wetlands, which, endures flooding on a less frequent basis and for shorter durations than mixed hardwood communities or cypress swamps. In the Gulf Coast area, limestone outcroppings are common (Hine et al., 1985) and trees can grow hydroponically on rock. Species assemblages are dominated by cabbage palm, red maple, live oak, water oak, and ironwood (SRWMD, Suwannee River Water Management District. 1998). This forest community occurs extensively throughout coastal regions of Florida, including the District.

Tidal Fresh-Water Swamps

Tidal swamps are tidally influenced forested areas in the upper regions of estuaries that are flooded daily by high tides and are dry at low tide through the year. Species composition includes bald cypress, pumpkin ash (indicator species) as well as cabbage palm, sweet and swamp bay and red maple. Exposed tree roots are often present on the forest floor (SRWMD, 1998). Tidal swamps in the nearby Lower Suwannee Wildlife Refuge were reported as being important nesting grounds for swallow-tailed kites (Sykes et al., 1999).

Tidal fresh-water swamps are the least understood and characterized of all coastal wetland systems in the southeastern U.S. (Tiner, 1993; Clewell et al., 1999). Although this habitat type could not be delineated based on the photography used by the District to produce the 1995 land use coverage, this habitat was reported to exist on the extreme lower portion of the Waccasassa River, as well as on the Lower Suwannee River (SRWMD, 1998). Field notes from the District's Waccasassa Estuary Salinity Monitoring Network also reported the occurrence of tidal swamps along the coast, near the mouth of the river (Giambrone and Mattson, 2004, pers. comm.).

Tidal Marshes

Coastal areas in the northeastern Gulf of Mexico, which include peninsular Florida, consist of an extensive, low-gradient plain that extends out into the Gulf in many places, such as Florida's "Big Bend" region (Clewell et al., 2002). In this area, frictional drag of moving water mitigates wave energy and protects the shoreline from erosion (Clewell et al., 2002; Tanner, 1960). These sheltered areas favor the establishment of tidal marsh habitat (Odum et al., 1984; Wiegert and Freeman, 1990; Tiner, 1993). Mangroves and tidal forest may also be present adjacent to the marshes in sub-tropical systems (Clewell et al., 2002).

The lower portions of tidal rivers, such as the Waccasassa, represent gradients of physical conditions due to differences in hydrologic head, topography and flow. Slope of the land, combined with fresh-water inflow and tidal exchange, largely determine inundation rates, substrate composition and salinities in the river and associated marshes. Conditions occur on a continuous, yet ever changing gradient, depending on river flow and tides. Specific areas within a tidal system are categorized based on their relative position along existing environmental gradients (Odum et al., 1984). Surface salinity (Cowardin et al., 1979) or interstitial salinity (Pearlstine et al., 1990) often constitute the basis for such categorization.

Tidal fresh-water marshes often represent the most upstream, low salinity, areas of overall marsh habitat. Dominant plants may include sawgrass, bulrushes, wild rice, cattail, and arrowhead among other fresh-water emergent plants (Clewell et al., 1999). Overall they have the highest plant diversity of the various tidal marsh communities.

Salt marshes represent the opposite end of the gradient for marsh communities. They are the least diverse with respect to plant communities and are often dominated by a single species. Dominant plants may include members of the cordgrass (Spartina) and needlerush (Juncus) genera (SRWMD, 1998).

2.9.2.2 Other Estuarine Habitats

Tidal Creeks

Tidal Creeks have been reported as representing the most important animal habitat in the tidal marshes (Montague and Odum, 1997). They note that "Tidal creeks are perhaps the key to some of the greatest values of intertidal marshland to estuarine animal life." (Montague and Odum, 1997; p. 19). The creeks provide access to the marshes for fishes and natant invertebrates (e.g., shrimp, blue crabs), they include shallow water bank habitat and submerged aquatic vegetation (SAV), which provides important nursery refuge for small fishes and invertebrates, and they are important feeding habitats for wading birds and waterfowl (Montague and Weigert, 1990). In a study done by Tsou and Matheson (2002) using juvenile fish data collected in the Florida Marine Research Institute's Fisheries Independent Monitoring Program in the Suwannee estuary tidal creeks were found to be an important variable accounting for the distribution and abundance of several important forage species.

Submerged Aquatic Vegetation

Beds of SAV are found within the Waccasassa Estuary as evidenced by its inclusion in the Big Bend Seagrasses Aquatic Preserve. These SAV beds are basic sources of primary production (Allan, 1995), and serve as important habitat for benthic macroinvertebrates (Bartodziej, unpub. manuscript; Thorp et al., 1997) and fishes (Bass and Cox, 1985).

Oyster Reefs and Bars

Oysters are present in the Waccasassa Estuary, although not in the form of named reefs as in the Suwannee Sound. These are likely composed primarily of the eastern oyster (*Crassostrea virginica*), with two species of mussels (*Brachidontes exustus* and/or *Ischadium recurvum*) being secondary members of the reefs. The oysters themselves are a harvestable economic resource. In addition to their economic importance, perhaps even more important, is the value of oyster habitats for estuarine invertebrates and fishes (Bahr and Lanier, 1981). Beck et al. (2000) designated oyster reefs a Primary Habitat Target for estuarine conservation in the northern Gulf of Mexico, with special emphasis on those found in the nearby Suwannee estuary.

2.10 Springs of the Waccasassa River Basin

2.10.1 Levy Blue Spring

Levy Blue Spring (Bronson Blue Spring) is located in a County park on the Little Waccasassa River near its confluence with the main stem of the Waccasassa River.

The spring bowl is semi-circular and approximately 156 feet in diameter (Rosenau et al., 1977; Figure 2-23). Maximum depth is approximately 9 feet. The bottom of the spring bowl is covered with sand and several small sand boils can be observed. Rosenau et al. (1977) reported that the vent was about 25 feet below the water surface and about 30 feet in diameter at its top. Openings up to 1 foot in diameter could be observed in the limestone near the bottom of the vent. Assuming that

Figure 2-23 Levy (Bronson) Blue Spring.

- The radius of the spring pool is 78 ft;
- Upper 1 to 3 feet of pool has vertical sides depending on stage within the pool, and
- Last 6 feet is a truncated cone 78 ft. in diameter at the top and 5 ft. in diameter at the bottom,

the volume of the pool ranges from about 60,000 to 98,000 $ft.^3$.

The margins of the spring bowl have been enclosed with a concrete wall (Figure 2-23). The park surrounding the spring includes grassy picnic areas, and there are swimming and diving platforms in the spring.

The spring discharges into a run that is approximately 40-50 feet in width (Rosenau et al., 1977; Scott et al., 2004) and 1,600 feet in length. The spring run discharges into the Little Waccasassa River approximately 1,100 feet upstream from the confluence with the Waccasassa River. Levy Blue Spring is widely considered the headwaters for the Waccasassa River.

While there is little submerged aquatic vegetation in the spring bowl, the bottom is covered with algae (Scott et al., 2004). The spring run contains abundant aquatic and emergent vegetation and is surrounded by a dense, lowland swamp forest.

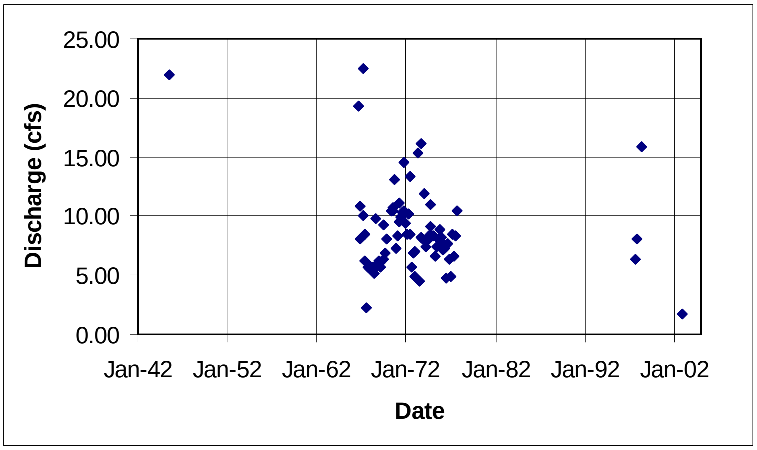

Figure 2-24 Historic discharge measurements at Levy Blue Spring. Data sources: Hornsby and Ceryak (2000), USGS. and District.

Discharge measurements from this historic third magnitude spring have ranged from 1.7 cfs during the record drought of 2002 to 22 cfs in 1945 and 22.5 cfs in 1967 (Figure 2-24; Rosenau et al., 1977; Hornsby and Ceryak, 2000; unpublished USGS data). Median discharge, based on the 80 measurements depicted in Figure 2-24, is 8.1 cfs. Rosenau et al. (1977) reported that the average of 56 discharge measurements taken from 1917 to 1974 was 8.9 cfs.

As shown in Figure 2-25, nitrate nitrogen concentrations are low in water discharging from Levy Blue Spring. Even so, there is an apparent trend of increasing concentrations with time.

2.10.2 Wekiva Spring

Wekiva Spring, a privately owned, second magnitude spring is not on the District's MFL priority list. However, it is important to discuss the spring because of its contribution to the discharge of the Waccasassa River.

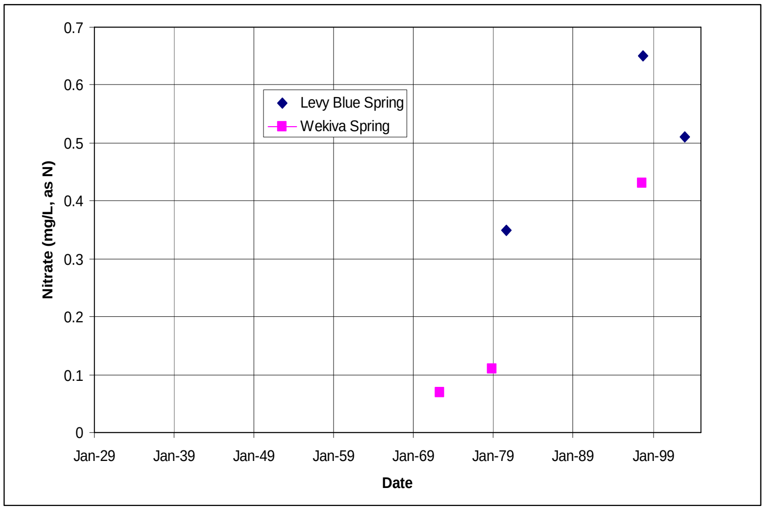

Figure 2-25 Nitrate concentrations in water discharging from Levy Blue and Wekiva Springs. Data from Hornsby and Ceryak (2000).

The spring (Figure 2-26) consists of three pools that are interconnected by open channels (Rosenau et al., 1977; Scott et al., 2004), all within a radius of approximately 150 feet.

The smallest pool is approximately 40-feet long and 20-feet wide. Flow is from an 8-foot deep hole in the bottom of the pool. Water from this pool discharges to the largest pool via a 185-foot run.

The largest spring pool is 125-feet long and 60-feet wide. The deepest part of the pool is about 30 feet, and Rosenau et al. (1977) observed a "strong" surface boil in 1972.

The discharge from the largest spring pool flows into the intermediate-sized spring by way of a narrow, 60-foot channel. The intermediate pool is approximately 50-60 feet in length and width and has a maximum depth of about 15 feet (Rosenau et al., 1977). It discharges by a run that is the headwaters of the Wekiva River, which joins the Waccasassa River approximately 7 miles downstream (Scott et al., 2004).

The surrounding land has been cleared and the spring run has a small dam on it. Limestone is exposed in the springs and channels, and there are limestone bridges and other, associated karst features. Water is currently removed from the spring for bottling, and access is restricted. Based on District records, the bottling operation began in 1992 and is currently permitted to withdraw 0.127 mgd on an average daily basis.

Henry Beck Park, a County park located on the Wekiva River (Figure 2-27), is the nearest public access to water from the spring.

Figure 2-26 Wekiva Springs.

Figure 2-27 Beck Park, a County park located on the Wekiva River.

The spring is clearly second magnitude, and the 55 historic discharge measurements (Figure 2-28) indicate that discharge is somewhat variable. Median discharge, based on the measurements shown in Figure 2-27, is 51.6 cfs.

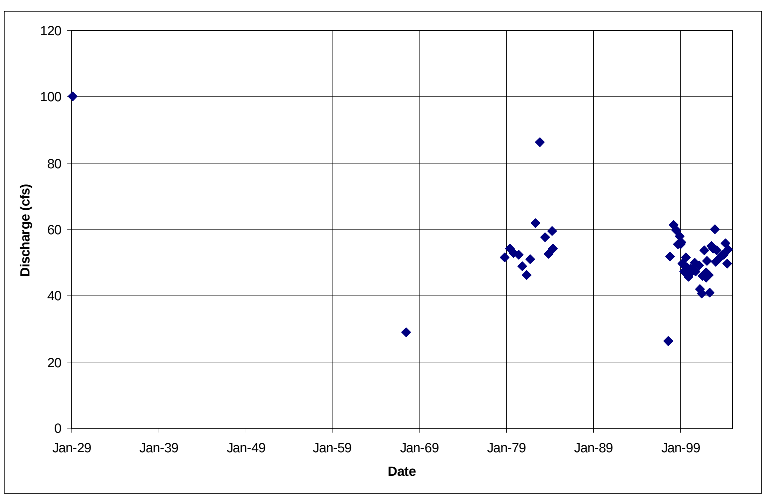

Figure 2-28 Historic discharge measurements from Wekiva Spring. Data sources: Hornsby and Ceryak (2000) and District.

As is the case with Levy Blue, nitrate concentrations appear to be rising (Figure 2-25), but they remain low relative to other springs in Florida.

2.11 Effects of Sea-Level Rise

As noted above, the Waccasassa River system and its springs are characterized by low-gradient riverine conditions. Recently, scientists from the University of Florida and the U.S. Geological Survey (Williams, Ewel et al., 1999; Williams, Pinzon et al., 1999) have shown that the sea level is rising and having adverse effects on the Waccasassa River estuary and coastal swamp. These effects include tree mortality and replacement of forest by salt marsh habitats. Figure 2-5 illustrates some of these dead trees in the upper estuary and mouth of the river.

As the sea level rises, there will be continued displacement of forest with coastal marsh habitat. In addition, it can be anticipated that, in the long term, the salt-water/fresh-water transition zone in the Floridan Aquifer will rise and move inland. As the fresh-water zone is reduced in extent, fresh-water flow from the springs will change and, therefore, discharge patterns in the Waccasassa and its tributaries will change.

TAB 3

3.0 Hydrologic Analyses

3.1 Data

This section presents a summary of the hydrologic and hydrogeologic data that are available for determining minimum flows and levels (MFLs) for the Waccasassa River Basin. As discussed in Section 2.1, the Waccasassa River Basin encompasses portions of Levy, Marion, Gilchrist, and Alachua counties (Figure 1-1). As shown in Figure 1-1, the study area consists of the Waccasassa drainage basin. Those portions of the U.S. Geological Survey (USGS) Waccasassa hydrologic unit that are internally drained or drain directly to the Gulf of Mexico are excluded from the study area.

The District provided all of the data, including data provided by the USGS, used in this report, unless otherwise noted. The data set includes information on groundwater levels and use, stream-gage data for the Waccasassa River, its tributaries and springs, and precipitation data. The following data summaries include gage data and direct measurements. Where both formats of data exist, the gage data, which provide time series data arrays, were utilized for analysis. Direct measurement data were utilized in the absence of daily gage data or to confirm statistically synthesized data.

3.1.1 Groundwater Data

3.1.1.1 Groundwater Levels

The District provided a complete record of groundwater-level data for monitor wells in its database within Levy, Gilchrist, and Alachua County for analysis. Of these, 32 wells were located within the Waccasassa River Basin study area (Figure 3-1), Table 3-1 contains information on these wells, including the dates of the first and last measurements used for this report, the frequency of measurement, the total number of measurements, and the minimum and maximum groundwater levels recorded within each well. Appendix A contains graphs of the complete data set for each of these wells.

Of these 32 wells, only two (wells # 25 and 26; Figure 3-1, Table 3-1) have been monitored on a daily basis for some period, and these were only continuously monitored for about three years each. The remaining wells were monitored on a monthly to quarterly basis. Some wells have significant gaps within their monitoring records.

Due to the lack of continuously monitored wells within the Waccasassa River Basin, several wells were identified which lie near, but outside of the basin that aid in the MFL development process. These wells (#33 – 36) are listed in Table 3-1 and their locations are shown on Figure 3-1. Appendix A contains graphs of the complete data set for these wells.

Groundwater elevations typically show similar patterns corresponding to the seasonal changes in rainfall (Appendix A). The range of water levels is typically between 5 and 20 feet annually. Overall, the potentiometric surface nears sea level at the coast and increases to around 60 to 65 feet above mean sea level around the headwaters of the Waccasassa River (Figure 2-10).

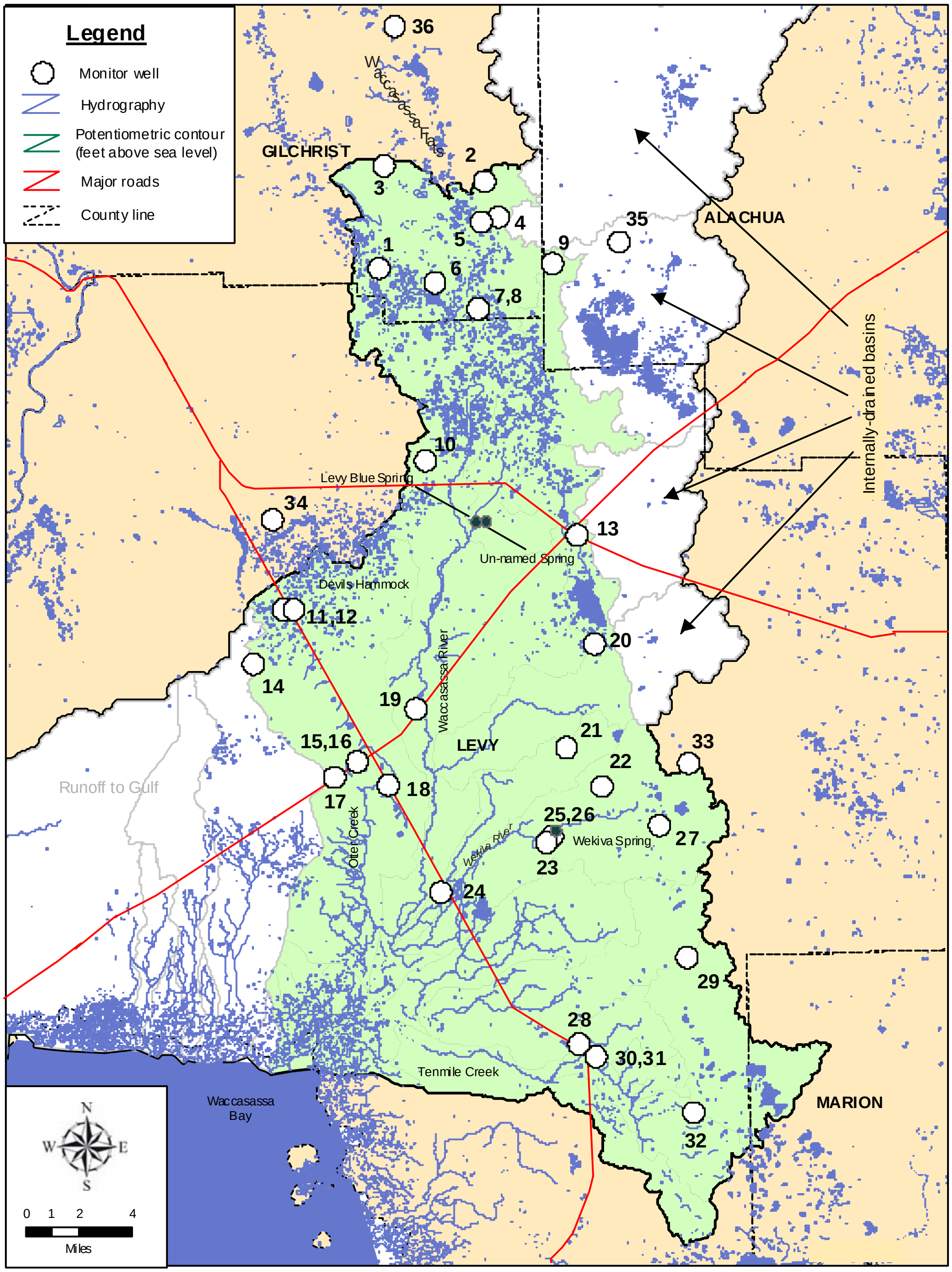

Figure 3-1. Groundwater monitoring wells within and near the Waccasassa River study area.

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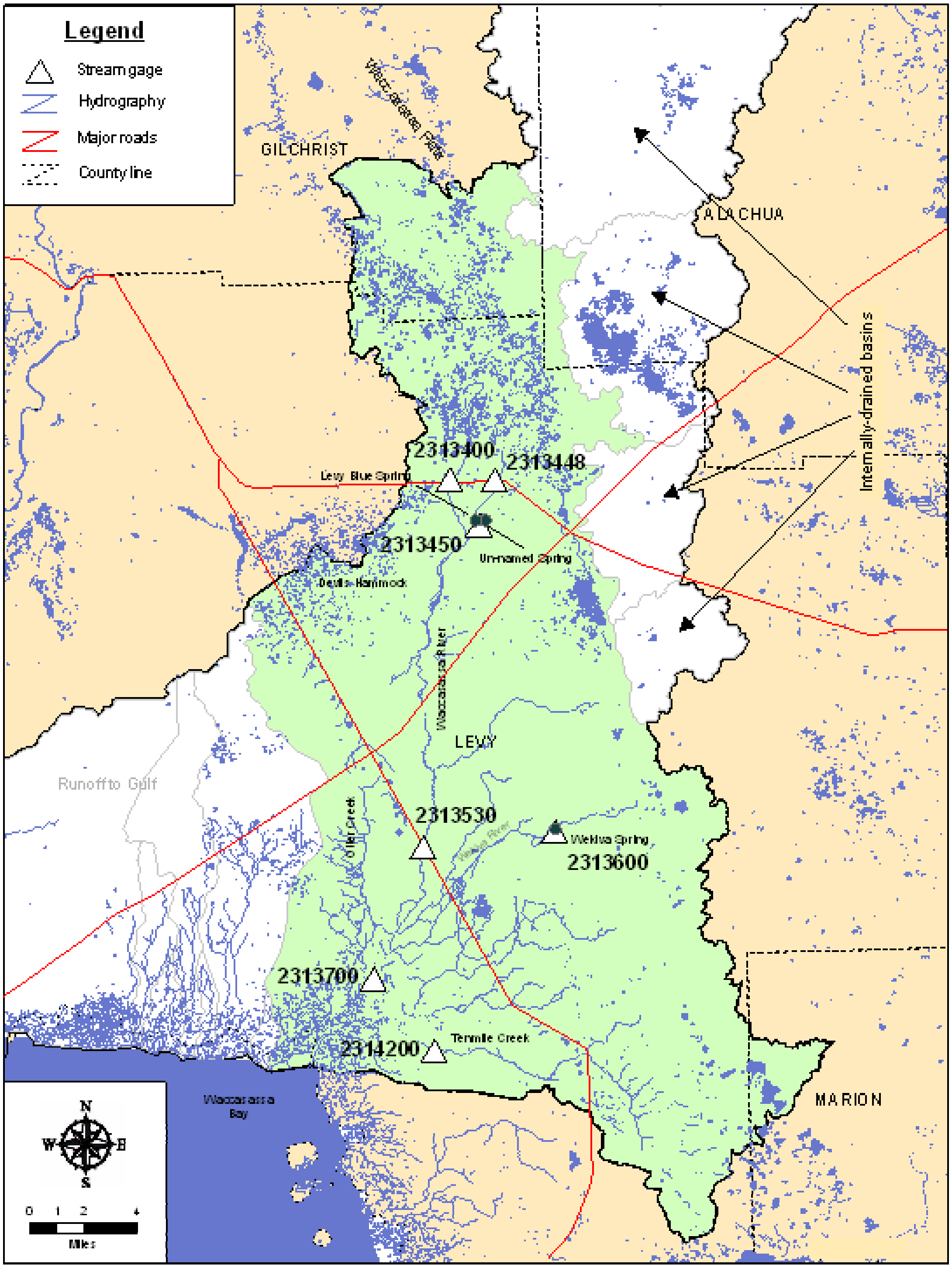

Figure 3-2. Stream gages located within the Waccasassa River basin.

Table 3-1 Water-level data available from monitoring wells located within the Waccasassa River Basin.

Well	Site ID	Date First Measured	Date Last Measured	Frequency Measured	Number of Measurements	Minimum (ft., NGVD	Maximum (ft., NGVD)
1	-101524001	10/01/1981	01/28/2004	Quarterly*	8	39.71	55.21
2	-101603001	11/01/1976	05/11/1998	Quarterly*	23	38.99	50.40
3	-101606001	03/23/1982	12/07/1982	Quarterly	4	86.63	89.18
4	-101614002	10/01/1981	12/08/1982	Quarterly	5	39.37	46.96
5	-101615010	10/08/1981	12/08/1982	Quarterly	5	86.45	92.27
6	-101628003	10/01/1981	12/08/1982	Quarterly	5	54.58	57.02
7	-101634001	06/27/1991	08/03/2004	Monthly	157	55.98	67.37
8	-101634002	06/27/1991	08/03/2004	Monthly	157	56.65	67.18
9	-101719001	11/16/2000	08/17/2004	Quarterly	15	36.95	45.10
10	-111632001	12/01/1976	12/07/1982	Quarterly	20	37.63	46.91
11	-121528001	12/01/1976	05/16/1990	Quarterly*	23	26.70	33.97
12	-121528003	12/06/2001	12/08/2004	Quarterly*	5	24.75	28.46
13	-121717001	09/14/1964	05/16/1995	Quarterly*	25	44.32	58.00
14	-131506002	01/26/1982	12/07/1982	Quarterly	5	23.36	26.16
15	-131526001	09/27/1983	09/02/2004	Monthly*	108	16.21	25.90
16	-131526002	09/09/1981	09/06/0988	Bi-monthly	37	15.93	21.99
17	-131527001	04/21/1981	12/07/1982	Monthly	23	18.84	23.49
18	-131536001	06/13/1989	12/12/1990	Monthly	19	18.78	22.66
19	-131617001	06/11/2004	09/02/2004	Monthly	4	26.52	29.39
20	-131705001	12/01/1976	08/08/2002	Monthly*	80	48.77	58.60
21	-131730003	06/13/1989	04/06/2004	Monthly*	23	41.15	46.19
22	-131732001	05/19/2004	09/02/2004	Monthly	5	44.93	47.36
23	-141612001	12/05/2000	09/02/2004	Quarterly*	10	21.92	27.89
24	-141620001	05/03/1968	09/02/2004	Monthly*	143	6.20	12.40
25	-141707002	10/07/1997	12/13/2000	Daily	1000	23.68	27.97
26	-141707004	12/13/2000	08/26/2004	Daily	1359	23.75	26.47
27	-141711001	02/01/1977	05/21/2002	Quarterly*	24	43.62	55.28
28	-151624001	11/01/1976	05/21/2002	Quarterly*	26	21.47	27.84
29	-151703001	12/01/1976	12/07/1982	Quarterly	21	40.46	51.99
30	-151719001	09/09/1981	09/01/1987	Bi-monthly	33	26.72	30.23
31	-151719004	06/07/2000	09/02/2004	Quarterly	16	24.51	30.54
32	-151734001	04/05/1982	05/21/2002	Quarterly*	9	49.76	61.53
33 #	-131736001	11/01/1976	09/29/2004	Daily	8,244	35.65	52.94
34 #	-121508002	10/03/1981	06/16/2000	Daily	6,356	23.68	37.32
35 #	-101722001	10/07/1965	09/17/2004	Daily	8,073	34.76	54.63
36 #	-091607001	11/01/1976	09/30/2004	Daily	7,874	39.51	76.49

* Large data gaps exist within the time series; # Well located outside of the Waccasassa River Basin.

Table 3-2. Stage and discharge measurements available for the Waccasassa River, its tributaries, and springs.

Stream Gaging Station			Period of Record	# of Measurements		# of Daily Gaged Values	
USGS Ref. #	SRWMD Site ID	Description		Stage	Discharge**	Stage	Discharge
02313400	-111633001	Waccasassa River near Bronson	02/07/1984-02/21/1998	20	1	--------	--------
02313448	-121602001	Little Waccasassa River near Bronson	09/18/1979-04/08/1998	33	16	--------	--------
02313450	-121610002	Blue Spring near Bronson	08/03/1945-04/07/2004	681	80	--------	--------
02313530	-141608005	Waccasassa River at Gulf Hammock at US 19	07/12/1996-06/30/2004*	2,724	44	--------	2,190
02313600	-141707001	Wekiva Springs near Gulf Hammock	02/01/1929-06/28/2004*	1,508	55	--------	2,116
02313700	-151502001	Waccasassa River near Gulf Hammock	04/01/1963-09/30/2005*	272	277	6,385	11,763
02314200	-151624002	Tenmile Creek at Lebanon Station	09/30/1962-06/28/2004*	171	125	9,902	12,790

- Data after 9/30/2003 are provisional. ** Data available in digital format.

3.1.1.2 Groundwater Use

Information was provided by the District on the existing groundwater withdrawal permits for Levy, Marion, Gilchrist, and Alachua Counties. There are currently 422 permits issued in Levy County, 401 permits issued in Gilchrist County, and 601 permits issued in Alachua County. However, as the study area lies primarily within Levy County (Figure 1-1), a majority of the permitted wells are likely to lie within Levy County. Available data on these permits includes permit holders name and address and the average and maximum daily rates of pumping allowed for the well. The water-use data are discussed in Section 2.7.

3.1.1.3 Groundwater Quality

Many of the wells that are currently being monitored (Table 3-1) are also sampled for geochemical indicators as part of the District's Water Assessment Regional Network (WARN). Where these data provide some use for MFL development, they are presented and discussed, as appropriate.

3.1.2 Surfacewater Data

3.1.2.1 Spring Data

Historic hydrologic data for Levy Blue and Wekiva Springs are shown in Figures 2-25 and 2-27, respectively. These data consist of direct measurements made during visitations to the springs. Table 3-2 lists the periods of record, the number of digital stage and discharge measurements, and the number of daily measurements of stage and discharge for each station. These data are presented graphically in Appendix B.

As noted above, where both direct measurements and daily gage data exist, the daily gage data were utilized in the following analyses because they provide nearly complete time-series data arrays.

3.1.2.2 River Discharge Data

Stage and discharge data were provided from seven gages in the Waccasassa River Basin (Table 3-2; Figure 3-2). Table 3-2 lists the periods of record, the number of direct stage and discharge measurements, and the number of daily gage measurements of stage and discharge for each station. These data are presented graphically in Appendix B.

The most complete and extensive data sets are from the gages on the Waccasassa River near Gulf Hammock (USGS Gage No. 02313700) and on Tenmile Creek at Lebanon Station (USGS Gage No. 02314200). Daily stage and discharge readings have been collected at these gages for the past 30 - 40 years, although there are gaps in the data.

The Gulf Hammock gage is tidally influenced (note the negative discharge values on Figure 3-3), which complicates the use of the data for MFL development. The data from the gage on the Waccasassa at Gulf Hammock at US 19 (USGS Gage No. 02313530) displays significantly less tidal influence, although the period of record for this gage is significantly shorter (about 7 years).

Data were also available from two additional gages located near the headwaters of the Waccasassa River: the Waccasassa River near Bronson (USGS Gage No. 02313400) and the Little Waccasassa River near Bronson (USGS Gage No. 02313448) (Figure 3-2). However, the available data for these gages is extremely limited (Table 3-2).

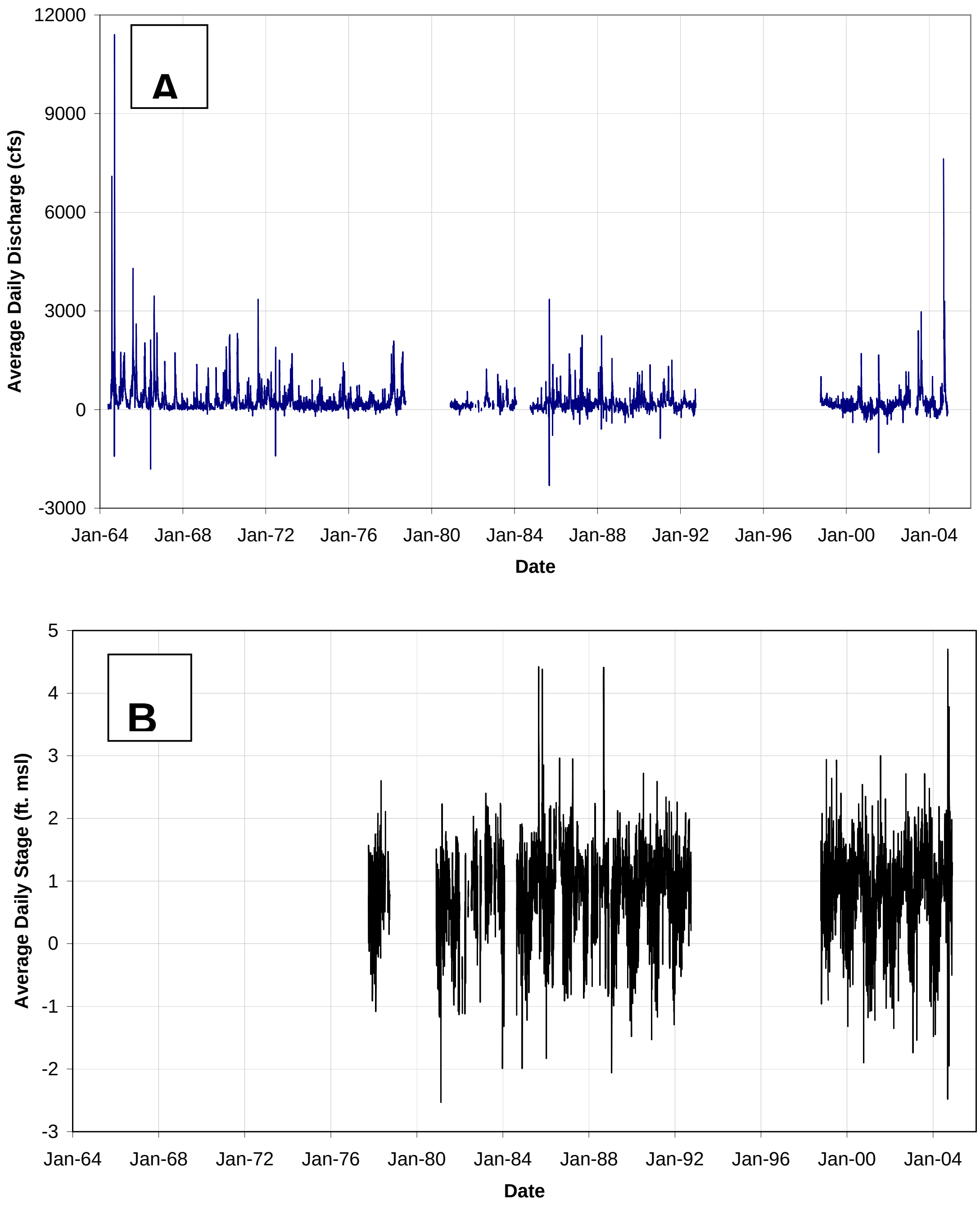

Figure 3-3 Discharge (A) and stage (B) data from USGS Gage No. 02313700, Waccasassa River at Gulf Hammock. Note the reversals in flow, which reflect tides and storm surges.

3.1.2.3 Tidal Data

As noted above, rivers and streams in the coastal portions of the Waccasassa River Basin are tidal. As such, their stage and discharge records reflect tidal fluctuations as well as wind set-up and storm surges. An attempt was made to remove as much of the tidal signal as possible by comparing the stream data with the tidal gage data from Cedar Key, the nearest National Oceanic & Atmospheric Administration (NOAA) tide gage.

Figure 3-4 shows the hourly tidal stage at Cedar Key for the month of December 1998. Note that the tides are mixed with a strong semi-diurnal component. Spring tidal range is approximately –3 to +2.5 feet relative to mean sea level, or about 5 feet in total. Neap tides are 2 feet or less in range.

Because of shallow water conditions in Waccasassa Bay and the Cedar Keys area, coastal waters are subject to wind stress as well as tidal fluctuations.

Figure 3-5 illustrates the average daily water levels at Cedar Key from November 1997 through October 2004. Note the seasonal pattern with low average stage in the winter months and high stage in the late summer. This is in part a result of seasonal wind and water temperature patterns and partly a result of seasonal runoff from the nearby mainland. Note also the high and low "spikes" in the record. These typically correlate with storm surges or lengthy wind set-up events.

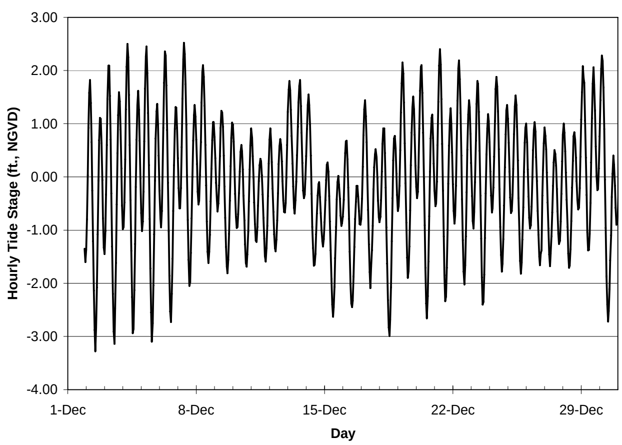

Figure 3-4 Hourly tidal record for December 1998 at the Cedar Key gage.

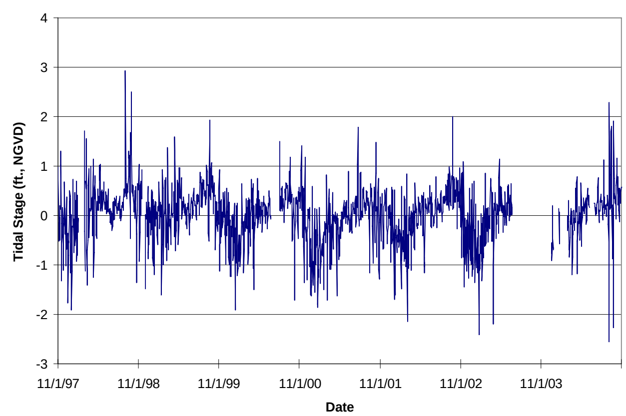

Figure 3-5 Daily average stage at the Cedar Key tidal gage. Note the high frequency "noise" caused by tidal variations in stage.

3.1.2.4 Precipitation Data

Monthly precipitation data exist for three stations in the vicinity of the Waccasassa River study area (Figure 3-6). The date first and last measured, along with the largest rainfall total for a single month at that gage, are presented in Table 3-3. The data are presented graphically in Appendix C. Two of the stations began recording data in 1976. The Usher Tower station began recording monthly data in 1956. Daily precipitation data at Usher Tower (Table 3-3) were obtained from NOAA.

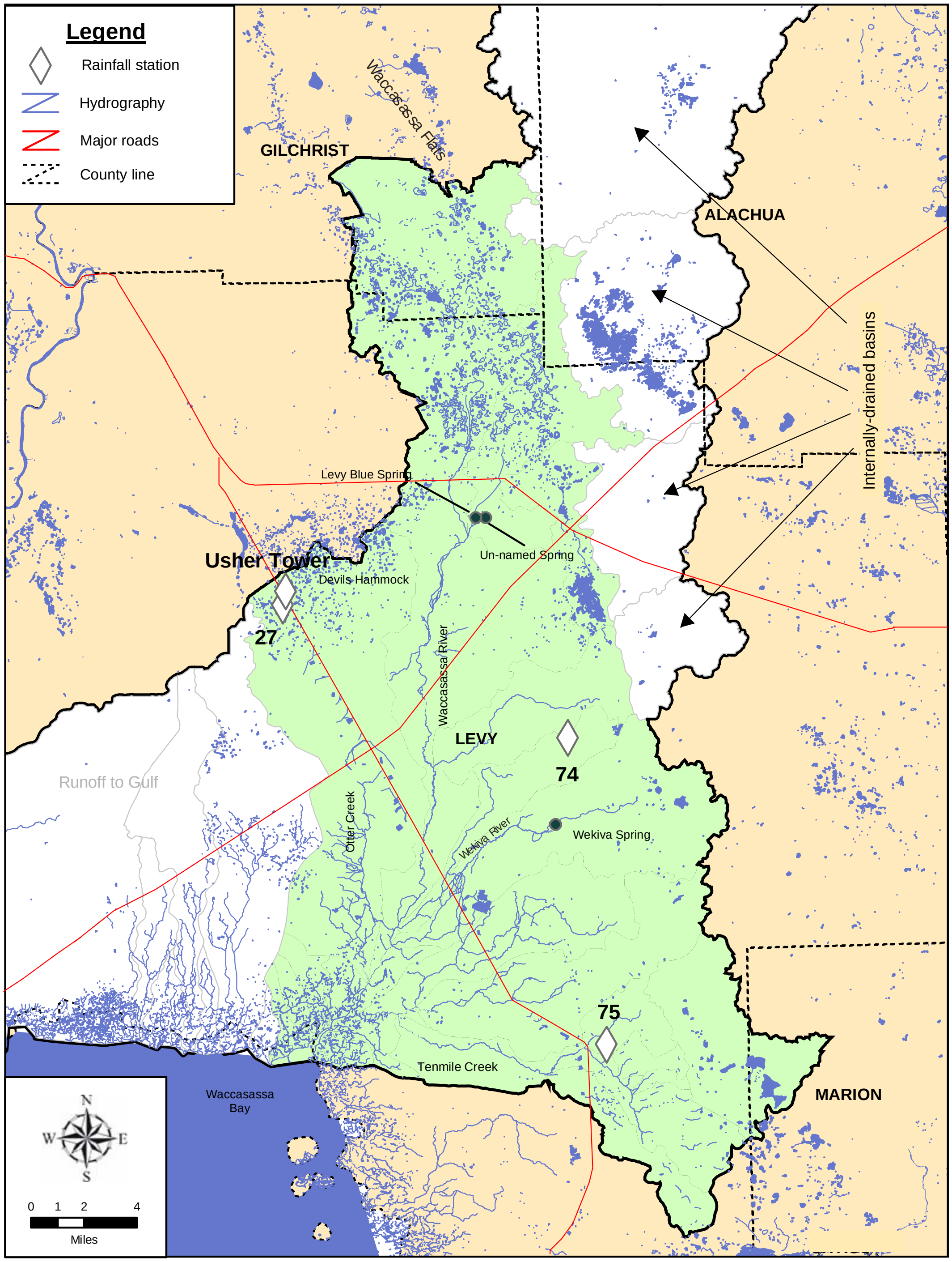

Figure 3-6 Locations of precipitation gages in the Waccasassa River study area.

Table 3-3 Available precipitation data in the Waccasassa River Basin.

Gage No.	Station	Type	Date First Measured	Date Last Measured	Maximum Event (Date)
27	Usher Tower	Monthly	July 1956	Present	20.8 in. (July 2001)
74	Wekiva Tower	Monthly	January 1976	Present	19.8 in. (February 1998)
75	Lebanon Tower	Monthly	January 1976	Present	23.9 in. (July 1978)
NOAA	Usher Tower	Daily	January 1, 1965	Present	8.41 in. (April 9, 1982)

3.1.3 Summary of Data Availability and Quality

The data available for the determination of minimum flows and levels for the Waccasassa River Basin include:

- Scattered and discontinuous stage and discharge data from several other gage stations that are distal to the coast;
- Continuous stage and discharge data for the tidal reach of the Waccasassa River at Gulf Hammock, Tenmile Creek at Lebanon Station, and from Wekiva Springs (periods of record range from 7 to 40 years);
- Quarterly, monthly, or bi-monthly groundwater level data which are discontinuous;
- Groundwater usage information;
- Monthly rainfall data from three stations;
- Daily rainfall data from Usher Tower (the only gage with a significant period of record); and,
- Tide information at the Cedar Key monitoring station.

Shortcomings of the available data include:

- The small amount of available recent data for Levy Blue Spring;
- The gaps in long-term stage and discharge data from the Waccasassa River;
- No data on actual water use;
- Data from the Waccasassa River gage at Gulf Hammock are tidally influenced; and
- Lack of daily groundwater level data from within the basin.

3.2 Data Analysis Methods and Uncertainties

3.2.1 Data Analysis Methods

The approach utilized for data analysis included several steps designed to condition the data and then determine hydrologic behavior of the Waccasassa River system. Methods used included the following steps:

1) Identification of data gaps and periods of insufficient record;

2) Preliminary identification of time lags between hydrologic responses at gage locations and gage rating curves;

3) Completion of data time series, where necessary, through multiple regression using time-lagged data;

4) Verification of time series data, including synthesized data, by comparison with measured stage and/or discharge data;

5) Development of final stage-discharge relationships utilizing original data augmented by synthesized data to fill data gaps;

6) Development of flow duration curves (FDCs) using the original, period-of-record data augmented by synthesized data to fill data gaps. These FDCs are termed the Baseline FDCs[1]; and

7) Identification of historic monthly flow and/or stage population descriptors using original data augmented by synthesized data to fill data gaps.

Data were first organized in Excel© spreadsheets for the analyses. Identification of data gaps and overall quality (Step 1, above), which have been discussed in Section 3.1, indicated that there were a number of gaps and that the coastal gage data were affected by tidal and storm-driven signals. Steps 2 through 7 were completed and the results are presented in the following sections.

Descriptive statistic functions in Excel© were used to calculate maxima, minima, percentiles, medians, and means. Cross-correlation analysis (Davis, 1986) was used to identify time lags between upstream and downstream hydrologic events. Multiple regression analysis (Davis, 1986; Helsel and Hirsch, 2002) was used to develop stage-discharge-rating equations for simulating flow of the Waccasassa River, its tributaries, and Levy Blue Spring. Graphical methods were applied to evaluate both data consistency and the relations and patterns between the hydrologic components.

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[1] Flow duration curves (FDCs) that are generated for the period of record of actual and synthesized discharge data are considered to represent baseline flow conditions. FDCs that are based on actual measurements only are termed historical FDCs. The baseline or historic FDCs are utilized as a basis for identifying water availability and setting MFLs. Once the MFLs are established, the MFL FDC indicates the amount of water available for use before significant harm occurs or the amount of recovery required to avoid continued significant harm.

3.2.2 Uncertainty Associated With Data Simulation

Whenever data synthesis is used to complete or extend a time series, there is a risk that "errors"[2] and uncertainties will compound because error (and uncertainty) is additive. To avoid compounded error, the calculated data were continually compared to raw data and residuals were tracked. There are usually multiple means for checking synthesized data at most gages. These methods include comparison of calculated values with either original gage data or with direct measurements of stage or discharge. In addition, based on the rating curve for the gage, there should be a reasonably predictable relationship between stage and discharge, so the discharge values can be compared to the contemporaneous stage values for consistency.

3.2.3 Other Sources of Uncertainty

The Waccasassa River, its tributaries, and the springs within the study area form a complex hydrologic system. The system has a low gradient and the lower river is affected by tides, storm surges, and wind set-ups near the coast. Due to this complexity, there is a level of uncertainty that goes along with simulating data for the Waccasassa River and its tributaries and springs. For example, discharge in the Waccasassa River Basin is related to many factors, including inflows from upstream, local precipitation, groundwater base flow, inflows from, or outflows to, springs, and the stage of the Gulf of Mexico within the Waccasassa Bay and estuary as a result of tides and storms. Lack of continuous records on these factors increases the simulation uncertainty.

The USGS daily discharge data from the Waccasassa River near Gulf Hammock gage (USGS Gage # 02313700) were used for setting the MFL for the Waccasassa River (Section 5). These data include tidal influences. However, after analysis it was determined that filtering of the tidal influences from the data set was not necessary because the salinity-discharge relationships required for MFL development were not overly influenced by the tidal signals.

3.3 Characterization of Discharge in the Waccasassa River System

Each of the gages in the Waccasassa River System is discussed below in turn, beginning with the most upstream gage at Levy Blue Spring and working downstream.

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[2] Error is a statistical term that refers to that portion of the variability in a data set that cannot be accounted for in a mathematical expression of the data. The term does not imply that the data are wrong, only that some proportion of the data variability cannot be fully accounted for by the analysis. The level of this statistical error is termed uncertainty. For example, if a regression equation accounts for 90% of the variability in the data, the error, which represents uncertainty in the analysis, is the remaining 10% of variability.

3.3.1 Levy Blue Spring (Gage 02313450)

While there are 80 discharge measurements from Levy Blue Spring, the majority (94% of the measurements) was collected sporadically from 1966 to 1977. In order to synthesize daily flows from the spring, contemporaneous groundwater head data are required. These data are not available for the period prior to 1990, which limited ability to develop an equation to predict daily discharge from the spring. Only four discharge measurements were available from Levy Blue Spring for a period where contemporaneous, daily groundwater level data were available (Figures 3-7 and 3-8). As this spring is on the District's priority water body list for MFL development, it was deemed necessary to attempt to generate a time series of discharge values in spite of the small number of available data points.

The monitoring well data from the Waccasassa River drainage basin were searched for a Floridan Aquifer well, from which daily water levels existed for the appropriate time frame. Water-level (head) data from Well No. –131736001 (Well No. 33, Figure 3-1) met the requirements and were used to simulate discharge data from Levy Blue Spring. Figure 3-10 illustrates these head data.

The head data were compared with discharge data from Levy Blue with the purpose of identifying the time lag that resulted in an equation that best fit the four Levy Blue discharge measurements.

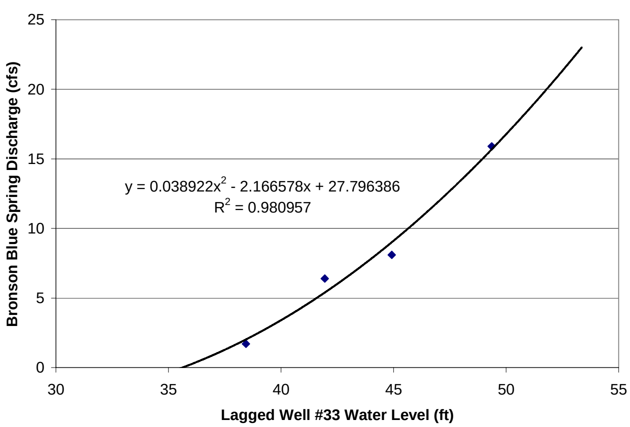


Figure 3-7 Relationship of potentials in Well -131736001 (Well 33, Fig. 3-1) with measured discharge from Levy Blue Spring.

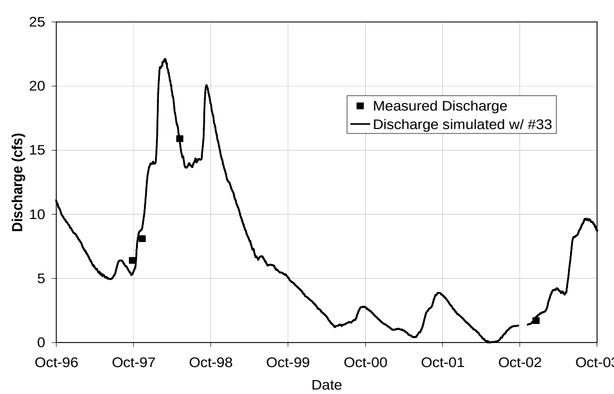


Figure 3-8 Discharge time series for Levy Blue Spring and comparison of estimated daily discharge with measurement data.

It was determined that there is an approximate lag of 33 days between potentiometric surface highs and highs in spring discharge. This time lag appears appropriate because of the distal location of the monitoring well and the known lag between recharge and discharge in similar areas of Florida. It is important to note that fitting only four points results in considerable uncertainty. Comparison of these four discharge measurements and the ground water hydrograph (Figure 3-9) for the time interval with the synthesized time series (Figure 3-8) strongly suggests that the data synthesis generates a credible pattern for the period from 1996 through 2003, however.

Based on the 33-day lag, a regression equation was developed between well water levels and spring discharge (Figure 3-7). With only four measurements of spring discharge, the associated uncertainty is high, and the "goodness of fit" metric (R^2 = 0.981) is probably over estimated as a result (i.e., 98.1% of the variability of the four data points was accounted by the analysis).

The regression equation (Figure 3-7) was utilized to generate a discharge time series for Levy Blue Spring (Figure 3-8). As a quality control measure, the actual discharge measurements for the time period during which groundwater levels are available are plotted on Figure 3-8~~9~~. Note that the simulation depicts a high in discharge during the el Niño rainfall event in late 1997 and early 1998. Note also that the simulated data also depict low flows during the record drought of 2000-2002. Based on these comparisons and the high R^2 value (0.981), these data constitute an acceptable synthesis of the daily spring discharge.

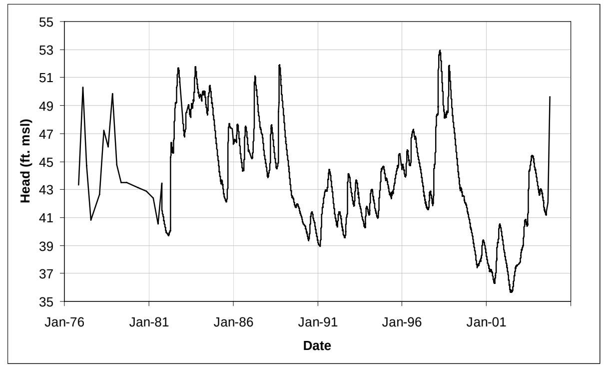


Figure 3-9 Water-level (head) data from Floridan aquifer Well -131736001 used to synthesize discharge from Levy Blue Spring.

The historical discharge data are depicted in Figure 2-24. Note that the majority of the measurements are centered in the late 1960s and early 1970s, a period of high rainfall. This causes a bias in the historical data that does not represent spring behavior during dry periods. The synthesized data are based on a range of rainfall patterns including high flow during the

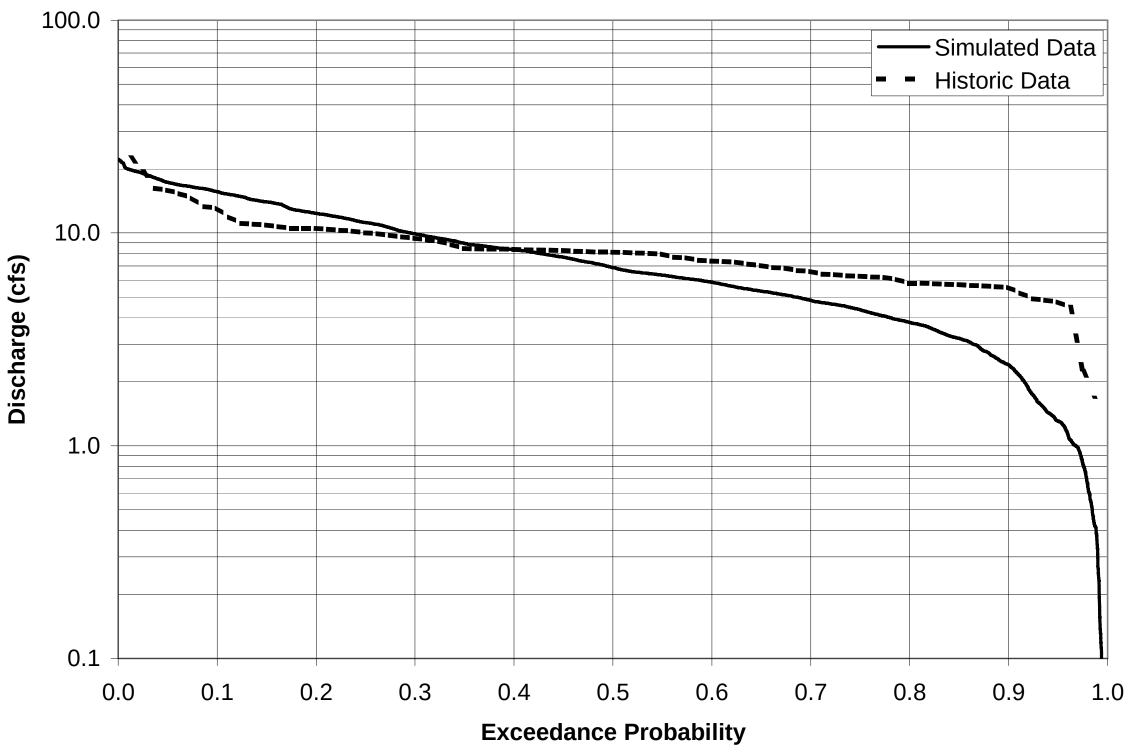


Figure 3-10 Simulated and historic flow duration curves for discharge from Levy Blue Spring.

1997-1998 el Niño rainfall event and low flow during the record drought of the early 2000s. Therefore, the synthesized data are thought to represent the “best available information” for the spring. The following analysis assumes that the simulated discharge data accurately reflect spring behavior. To test this assumption, the simulated data are compared to the historic data below.

Table 3-4 Population Metrics for the Simulated Flow of Levy Blue Spring Discharge (n = 8,819 simulated data points).

Period	Minimum (cfs)	0.75 Exceedance Probability (cfs)	0.5 Exceedance Probability (cfs)	0.25 Exceedance Probability (cfs)	Maximum (cfs)
Annual	0.0	4.3	6.9	11	22
January	1.1	3.4	7.2	10	21
February	1.0	3.7	6.7	10	22
March	0.5	4.7	6.5	10	22
April	0.09	4.4	6.5	11	19
May	0.0	4.6	6.2	9.5	16
June	0.04	4.4	6.3	9.9	17
July	0.3	4.7	6.4	12	18
August	0.9	4.6	8.3	13	20
September	1.3	5.2	8.6	14	20
October	2.3	4.8	8.3	12	19
November	1.4	4.2	7.6	11	17
December	1.4	3.8	7.3	11	16

Based on the simulated data, a baseline flow duration curve can be generated for Levy Blue Spring (Figure 3-10). As will be discussed below, the contribution of flow to the Waccasassa River at U.S. 19 (Figure 3-8) and this flow duration curve were utilized to set the MFL for the spring. For comparison, Figure 3-10 depicts the flow duration curves (FDCs) for both the simulated daily data and the sporadic measurement data collected from 1966 through 1977. The historic data depict similar median and high flow conditions, but differ with respect to low flow conditions. The simulated data include the record drought of the early 2000s, so this difference is not unexpected.

Table 3-4 presents the annual and monthly population metrics (population descriptors) for the simulated flow duration curve. The simulated data confirm that Levy Blue is a third magnitude spring according to the definition adopted by the Florida Geological Survey (Copeland, 2003) with a median flow of approximately 7 cfs (the median flow from the historic data is 8 cfs).

Figure 3-11 and Table 3-4 depict monthly box and whisker plots and summary statistics, respectively, of simulated discharge from Levy Blue Spring. As is typical of many springs, there is little month-to-month variability in discharge. There is a slight increase in median discharge near the end of the rainy season in August and September and a small decline in May, June, and July – a lagged response to the April-May dry season.

Based on a pool volume that ranges from 60,000 to 98,000 ft.^{3} depending on pool stage (Section 2.10.1), the median residence time of water in the spring pool is 0.3 to 0.5 hours.

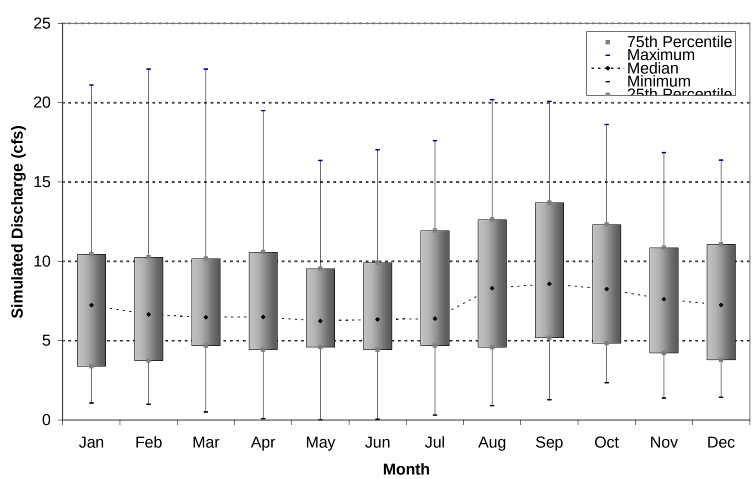


Figure 3-11 Box and whisker diagram showing monthly percentile and extreme flows based on estimated Levy Blue Spring discharge.

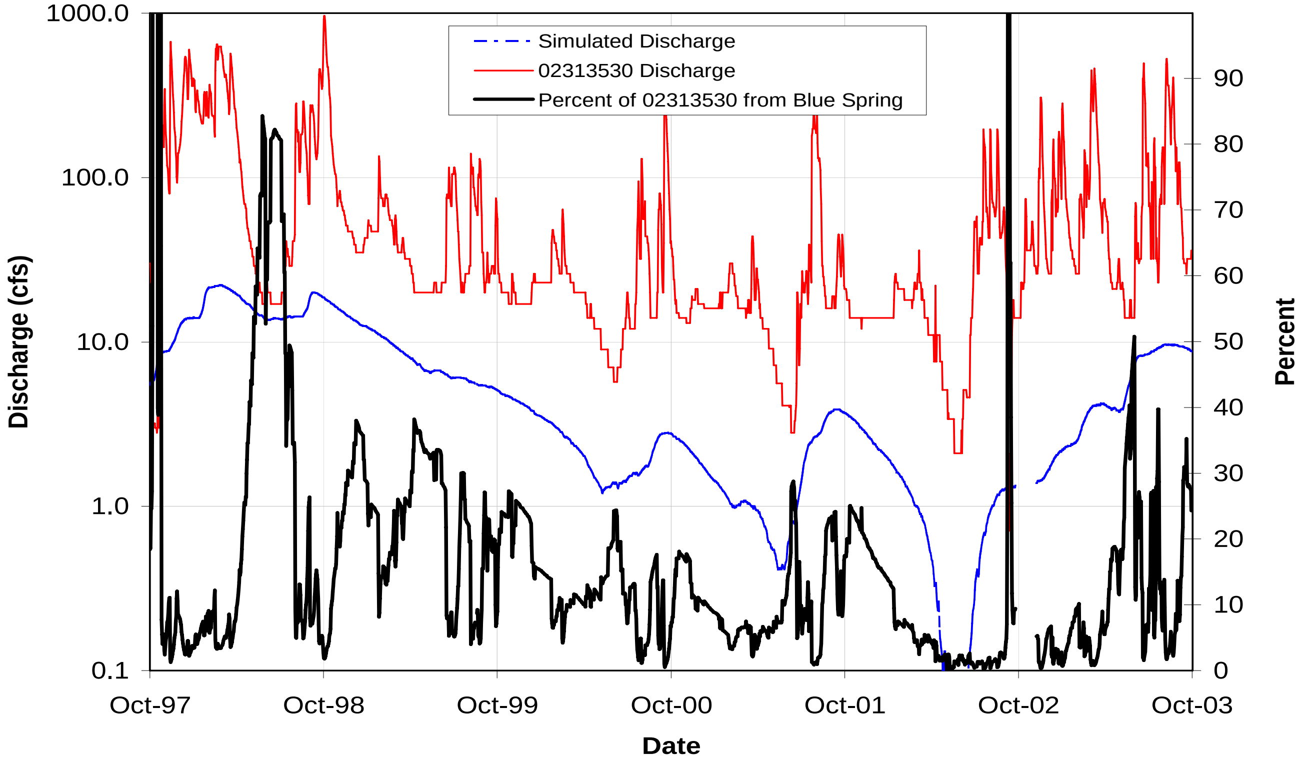


Figure 3-12 Comparison of discharge at the US 19 gage (Gage No. 02313530) with simulated discharge from Levy Blue Spring. The estimated proportion of river discharge derived from the spring is also shown.

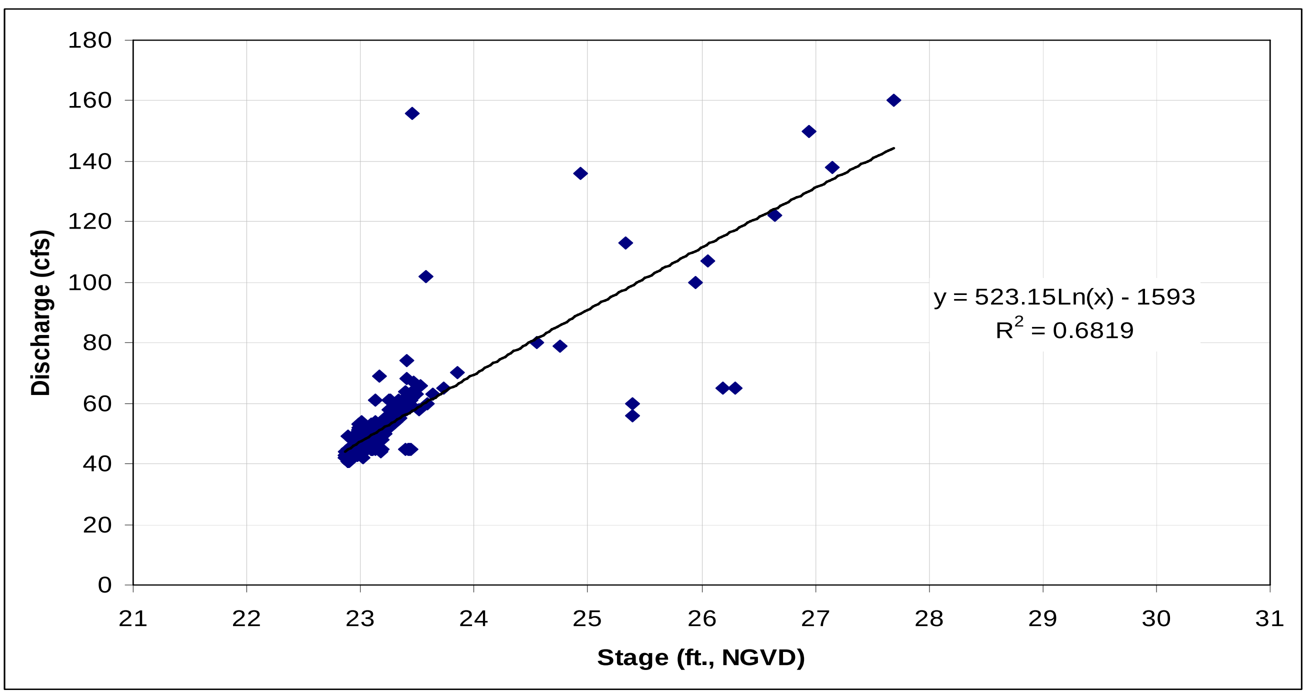


Figure 3-13 Comparison of stage and discharge data from the gage at Wekiva Springs.

Because the Levy Blue Spring pool is utilized for public bathing and because it is large relative to the median flow of the spring, the exchange of water in the pool was compared to the requirements of Chapter 64E-9 F.A.C. (Swimming Pools and Bathing Places). This rule requires that bathing water have a flow through of 500 gallons per bather per 24 hours. Thus, flow does not appear to limit use of the spring pool for recreational bathing. Based on the flow-through requirement, the current capacity is about 9,000 persons per day. The current use load, while not specifically known, is at least an order of magnitude less than this. In other words, the 500 gallons per bather requirement is not limited by flow in the spring.

Using the simulated discharge data, it is possible to evaluate the role Levy Blue Spring plays as a source of water in the Waccasassa River. Figure 3-12 displays the discharge pattern at the stream gage located on US 19 (Gage 02313530, Waccasassa River at Gulf Hammock at US 19) compared to the simulated Levy Blue Spring discharge. In addition, the proportion, as a percentage, of the river flow estimated to have been derived at Levy Blue Spring is shown. In general, the spring appears to contribute approximately 10 to 25 percent of the river discharge at US 19. At high river flow, this percentage drops to less than 5%. Note that at low river flow the percentage exceeds 100%. This may be an artifact of either (1) the simulation being unable to characterize extreme low flows, (2) losses through evapotranspiration as the water flows through the Devils Hammock swamp, or (3) wind set-up events temporarily reducing discharge in the lower portion of the Waccasassa River.

3.3.2 Little Waccasassa River near Bronson (Gage 02313448)

There are only 16 measurements of discharge from in the Little Waccasassa River (Table 3-2), and these are widely spaced over a twenty-year period. Furthermore, much of the discharge of the Little Waccasassa at the location where it joins the Waccasassa River is from Levy Blue Spring. As such, it was not considered necessary to synthesize discharge data or develop a flow duration curve (FDC) for this gage location.

Table 3-5 presents the annual baseline discharge metrics for the Little Waccasassa River.Median flow is about 8 cfs based on the existing data.

Table 3-5 Population Metrics for Historic Flow of the Little Waccasassa River near Bronson (n = 16 data points**).**

Period	**Minimum** (cfs)	**0.75 Exceedance Probability** (cfs)	**0.5 Exceedance Probability** (cfs)	**0.25 Exceedance Probability** (cfs)	**Maximum** (cfs)
Annual	0.0	3.6	7.9	19	76

3.3.3 Waccasassa River near Bronson (Gage 02313400)

As indicated by Table 3-2, there is only one discharge measurement at this location. Twenty stage measurements have been made over a 14-year period. Because of the lack of discharge data, it was not possible to synthesize estimated discharge over time. Therefore, data from this gage were not utilized in MFL development.

3.3.4 Wekiva Springs near Gulf Hammock (Gage 02313600)

There are 55 historic, direct discharge measurements (Section 2.10.2) from Wekiva Springs. The median discharge from these historic data is 51.6 cfs.

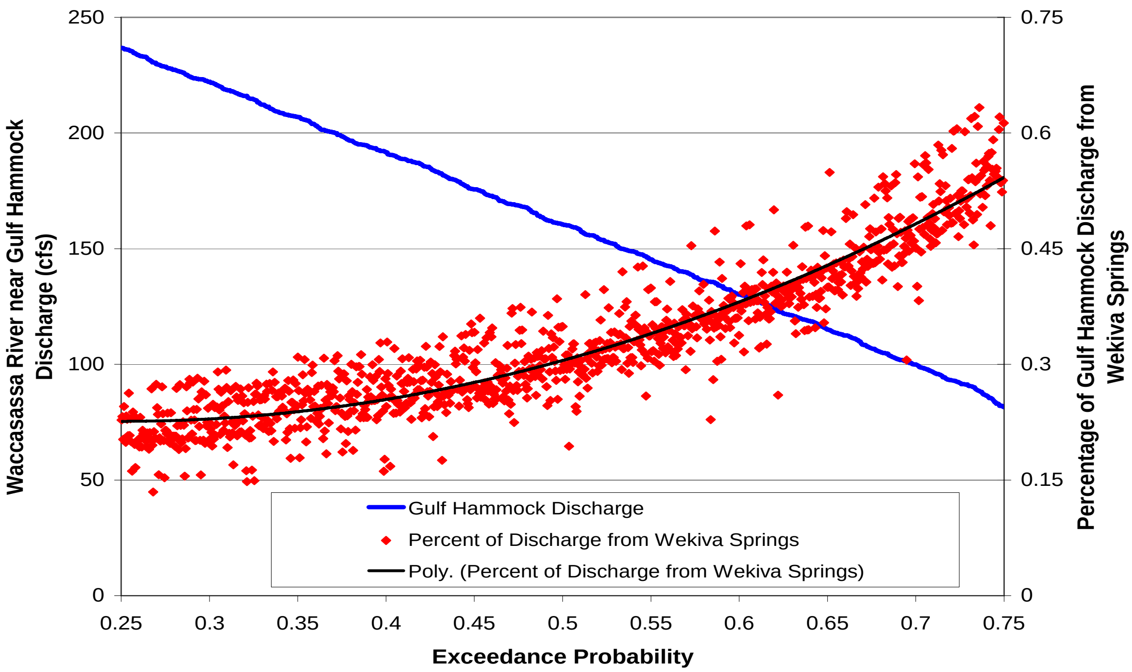


Figure 3-14 Estimated percentage of Waccasassa River flow at the gage at the mouth of the river (Gage 02313700) contributed by Wekiva Springs. See the text for a description of how graph was derived.

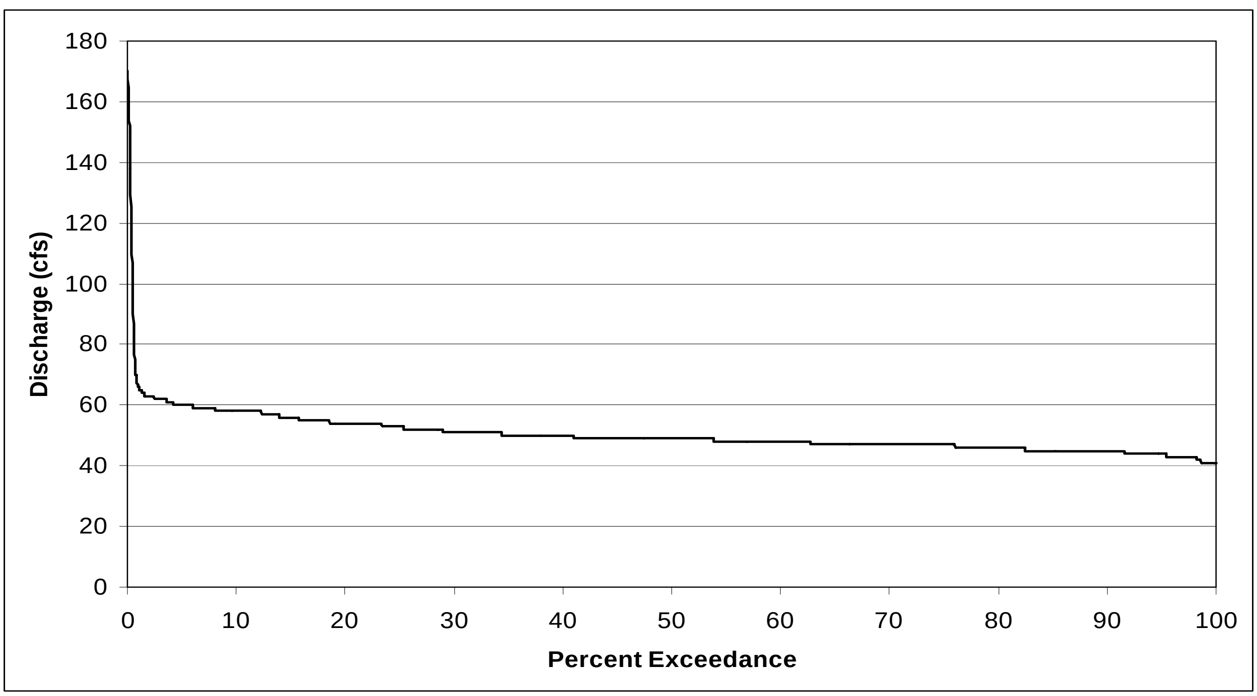


Figure 3-15 Baseline flow duration curve for discharge at Wekiva Springs.

Since 1997, the bottled water company that withdraws water from the spring has collected daily stage data. The District uses these data to calculate daily values for discharge through the use of a rating curve.

Figure 3-13 depicts the relationship of stage and discharge from this gage. At low discharge (approximately 40-65 cfs), the relationship between stage and discharge appears relatively linear. Above 65 cfs, there is considerable spread in the data. The cause of this spread is unclear, though it may be related to a variable backwater condition.

The Wekiva River empties into the Waccasassa River downstream from the US 19 gage. Therefore, the only Waccasassa River gage that includes discharge from Wekiva Springs is the gage at the mouth of the river (Gage 02313700, Waccasassa River near Gulf Hammock). However, data from this gage are affected by tides, storm surges, and wind set-ups (see Section 3.1.2.2). In order to compare discharge data from the two gages, a 7-day moving average was first applied to filter out short-term tidal effects in the Gulf Hammock discharge data. This averaged discharge was sorted from highest to lowest, along with the corresponding Wekiva Springs discharge, ranked and assigned an exceedance probability (values here differ from the period of record flow duration curve for the Gulf Hammock gauge because only the period of time with data for Wekiva Springs is considered). Then the upper and lower 25% of the values were dropped to remove data affected by longer-term tide, storm and flood events. Then Wekiva Springs discharge was divided by the averaged Gulf Hammock discharge to calculate a percent contribution from the springs to Waccasassa discharge at Gulf Hammock during moderately low to moderately high discharge periods (these are the times when Wekiva Springs discharge is significant to the river).

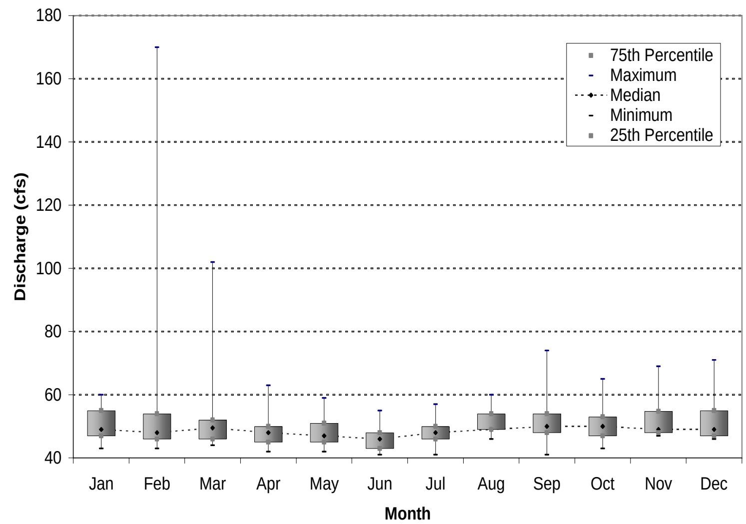


Figure 3-16 Box and whisker diagram illustrating median and ranges of monthly flows from Wekiva Springs based on data from Gage No. 02313600.

As Figure 3-14 shows, the percent contribution from Wekiva Springs to Waccasassa discharge at Gulf Hammock during these moderate flow periods ranges from 15 to 60 %, being much more significant during low river flows than during high river flows. During median flow conditions in the river, the contribution from Wekiva Springs is approximately 30%. The rate of increase in contribution form the springs is much more rapid above median flow in the river than below the

Figure 3-15 illustrates the baseline flow duration curve for the Wekiva Springs discharge data. Table 3-6 presents the summary statistics for the annual, baseline flow duration curve as well as summary statistics for monthly discharge.

A box and whisker graph (Figure 3-16) also depicts the monthly range of discharge from the springs. Note that the lowest median monthly discharge (Table 3-6; Figure 3-16) is in June, during the dry season.

3.3.5 Waccasassa River at Gulf Hammock at US 19 (Gage 02313530)

The gage on the Waccasassa River at Gulf Hammock at US 19 has been continuously monitored since 1996 (Table 3-2). The data from this gage are also affected by tides, but to a lesser extent than the gage at the mouth of the river (Gage No 02313700). While these data span a relatively short period, the lack of significant tidal signal and influences from the Gulf makes this gage important.

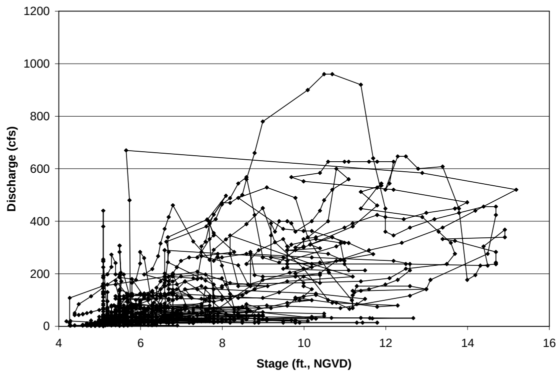


Figure 3-17 Relationship of stage and discharge of the Waccasassa River at the gage on US 19.

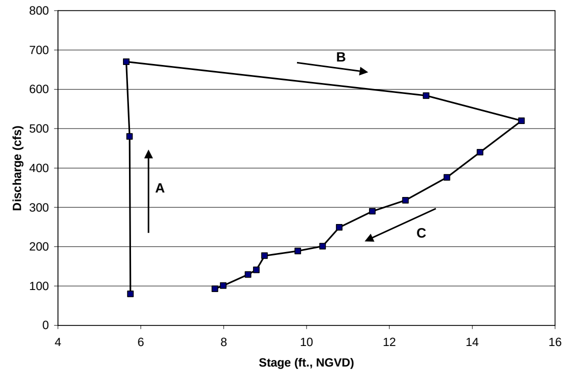


Figure 3-18 Stage-discharge relationships for a flood in the Waccasassa River upstream of the gage at US 19 during November 1997.

Table 3-6 Population Metrics for the Historic Flow from Wekiva Springs. (n = 2,116)

Period	**Minimum** (cfs)	**0.75 Exceedance Probability** (cfs)	**0.5 Exceedance Probability** (cfs)	**0.25 Exceedance Probability** (cfs)	**Maximum** (cfs)
Annual	41	47	49	53	170
January	43	47	49	55	60
February	43	46	48	54	170
March	44	46	50	52	102
April	42	45	48	50	63
May	42	45	47	51	59
June	41	43	46	48	55
July	41	46	48	50	57
August	46	49	49	54	60
September	41	48	50	54	74
October	43	47	50	53	65
November	47	48	49	55	69
December	46	47	49	55	71

Figure 3-17 illustrates the relationships of stage and discharge at the US 19 gage of the Waccasassa River. There are two important patterns in these data. First, note the looping patterns that develop at high stage and discharge. Figure 3-18 depicts one of these "loops", which occurred between November 11, 1997, and November 27, 1997 (during the record el Niño rainfall event of late 1997 and early 1998). Arrows and stage-discharge segments of the flood loop have been placed on the figure to illustrate the timing sequence. The flood begins with an increase in discharge accompanied by little change in stage (Segment A, Figure 3-18). This is followed by a slight reduction in discharge, but a significant increase in stage (Segment B). In the late stages of the flood event, the stage and discharge drop together (Segment C).

Table 3-7 Baseline Discharge Statistics for the Waccasassa River at US 19 (Gage 02313530). (n = 2,190)

Metric	**Minimum** (cfs)	**0.75 Exceedance Probability** (cfs)	**0.5 Exceedance Probability** (cfs)	**0.25 Exceedance Probability** (cfs)	**Maximum** (cfs)
Annual	0.71	16	26	67	960
January	14	21	32	74	392
February	16	22	39	79	647
March	11	20	32	164	568
April	5.1	12	20	29	201
May	2.1	5.6	13	20	37
June	2.1	5.7	17	29	497
July	12	23	33	65	273
August	14	43	79	159	529
September	0.71	22	32	80	640
October	2.8	14	20	39	960
November	12	17	26	75	670
December	14	16	26	73	600

The increase in discharge without accompanying stage increase (Figure 3-18, Segment A) appears to reflect initial flooding of the riparian swamps, including Devils Hammock, upstream of the gage. The lack of significant stage response is apparently a result of low surface roughness and flow retardation as the flood overtops the stream channel and enters the swamp floodplain. Segment B reflects the final flooding of the swamp. In this segment, water levels reach equilibrium within the swamp and stream channel and discharge is dispersed across a higher cross sectional area. Segment C reflects the ebbing of the flood with draining of the

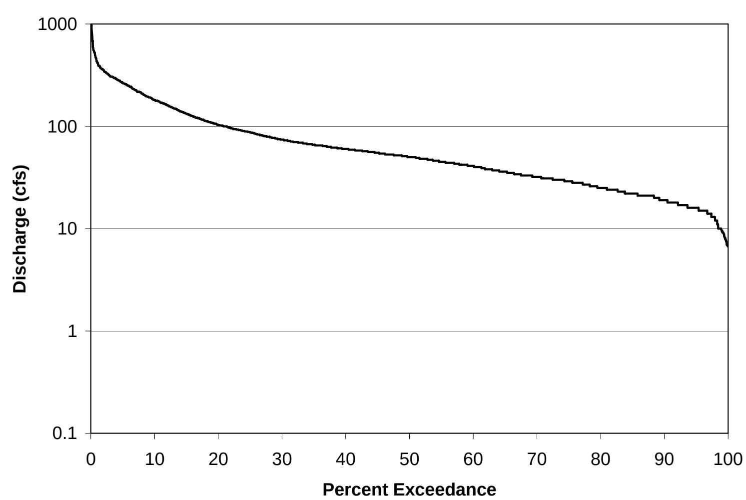


Figure 3-19 Historic flow duration curve for the Waccasassa River at US 19 (Gage 02313530).

floodplain. Here, the stage and discharge are reduced as the swamp drains. Based on this one flood loop, it appears that the flood plain is inundated at a discharge of approximately 500 cfs.

Figure 3-19 depicts the baseline flow duration curve for the Waccasassa River at US 19. These data are summarized in Table 3-7, as well.

As illustrated in Figure 3-20 and Table 3-7, lowest flow in the river is in the dry season, with minimum median discharge occurring in May. Floods typically occur at the end of the rainy season (August). As indicated by Table 3-7, high flood events have occurred in all months except May.

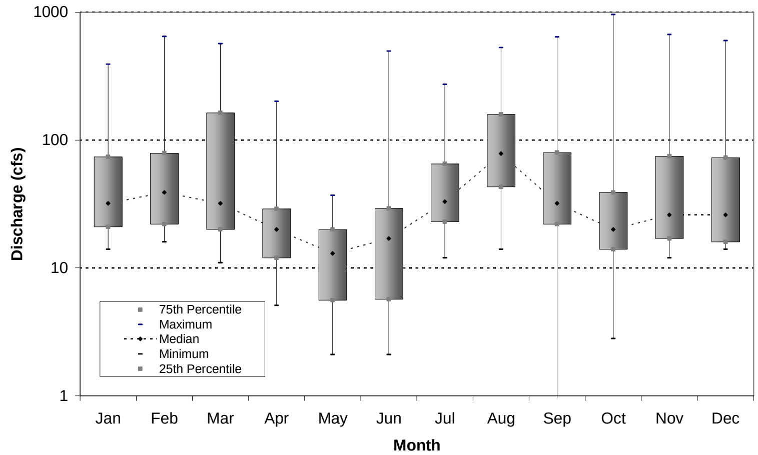


Figure 3-20 Box and whisker diagram illustrating the monthly variation in discharge of the Waccasassa River at US 19 (Gage 02313530).

3.3.6 Waccasassa River near Gulf Hammock (Gage 02313700)

The gage nearest the mouth of the Waccasassa is the gage known as Waccasassa River near Gulf Hammock (Gage 02313700; "Gulf Hammock gage"). This gage has been in operation since 1963 and the record is extensive. As noted above (Section 3.1.2.2), stage and flow at the gage are highly affected by tides, storm surges, and wind set-up events. As a result, it is occasionally difficult to differentiate between stream flow events and Gulf-related events.

Figure 3-21 illustrates the relationship of stage to discharge in the raw data from the Gulf Hammock gage. The pattern clearly reflects the importance of tidal fluctuations on the data. Note that the primary response is a change in stage with little or no change in discharge.

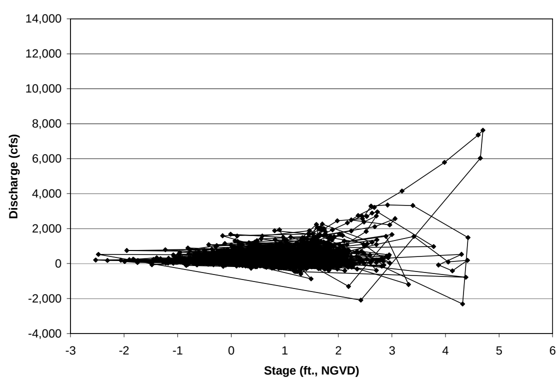


Figure 3-21 Comparison of stage and discharge data from the Gulf Hammock gage (02313700).

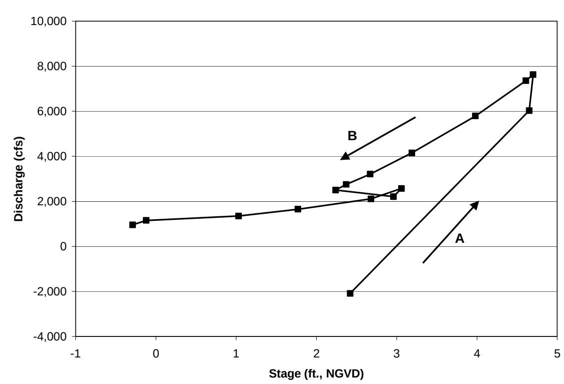


Figure 3-22 Stage-discharge relationships at the Gulf Hammock gage during Hurricane Frances (September 6-21, 2004).

The looping, stage-discharge pattern that extends to the upper right (arrow; Figure 3-21) represents a typical storm response. This event occurred in September 6 through September 21, 2004, which coincides with Hurricane Frances. Figure 3-22 isolates this sequence of data and demonstrates a single flood event. Note that the rising and falling limbs (Segments A and B) of the loop are nearly parallel and that the loop began with negative discharge on September 6. The negative flow reflects a building storm surge related to the hurricane, which reversed flow in the river and flooded the coastal marsh and nearshore portions of the coastal swamp. As a result, stage increased and there was significant storage of water in off-channel portions of the river system during Segment A. As soon as the surge abated, the inundated areas began to slowly drain (Segment B), increasing the discharge and causing stage to slowly drop.

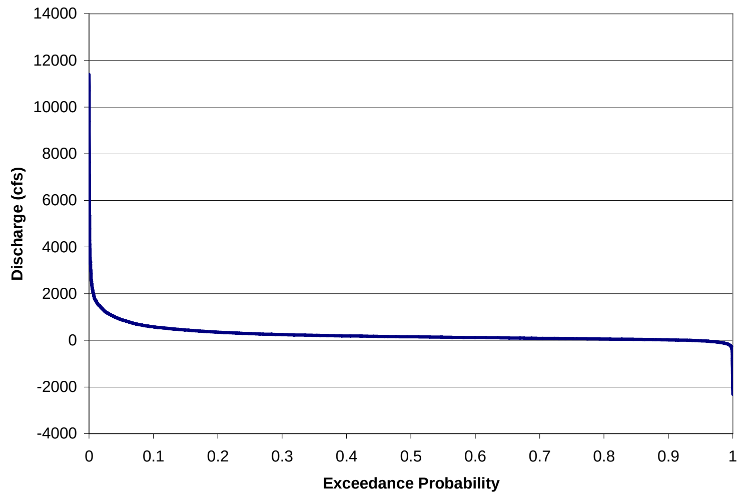


Figure 3-23 Historic flow duration curve for discharge data from the Gulf Hammock gage (Gage 02313700).

The baseline flow duration curve for the gage at Gulf Hammock (Figure 3-23; Table 3-8) includes the artifacts of tides, storm surges, and smaller wind set-ups. As shown in Sections 5 and 6, the data from the Gulf Hammock gage (Gage 02313700) are used for MFL establishment and evaluation. Therefore, the raw gage data are appropriate for use for the historic, or baseline, FDC.

The seasonal pattern at the gage is also disrupted somewhat by the storm and wind set-up effects of the Gulf of Mexico (Table 3-8; Figure 3-24). Lowest median flow is at the end of the dry season (May and June), and highest flows are at the end of the rainy season (August and September). There is also a peak median flow period in February, which coincides with rainfall derived from continental fronts that approach the area from the west and north.

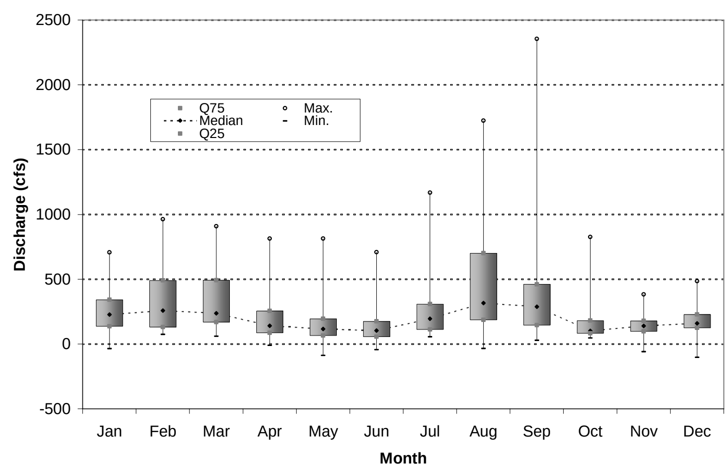


Figure 3-24 Box and whisker diagram showing monthly discharge at the Gulf Hammock gage.

Note that Table 3-8 and Figure 3-24 demonstrate the importance of summer storms, including tropical storms and hurricane activity. Maximum and 75th percentile flows are highest in September – the most active month of the hurricane season.

Table 3-8 Summary Statistics for Discharge Data from the Gulf Hammock gage. (n = 11,763)

Period	**Minimum** (cfs)	**0.75 Exceedance Probability** (cfs)	**0.5 Exceedance Probability** (cfs)	**0.25 Exceedance Probability** (cfs)	**Maximum** (cfs)
Annual	-2310	74	153	290	11400
January	-876	101	198	333	1680
February	-445	123	244	486	1940
March	-594	116	231	436	2240
April	-391	57	126	226	2270
May	-400	28	80	153	1820
June	-1810	38	98	175	2395
July	-1310	79	147	278	7090
August	-2310	134	270	644	4290
September	-1420	113	223	467	11400
October	-780	66	121	228	2720
November	-309	62	124	188	1370
December	-445	75	144	219	1740

3.3.7 Tenmile Creek at Lebanon Station (Gage 02314200)

Tenmile Creek is a tributary of Cow Creek (Figure 1-1), which discharges into Waccasassa Bay downstream from the Gulf Hammock gage (Gage 02313700). The Tenmile Creek gage has been monitored, off and on, since 1962 (Table 3-2). As the base level of Tenmile Creek at Lebanon Station is approximately 18 ft above mean sea level, this gage is not influenced by normal diurnal tidal fluctuations in the Gulf. However, storms do have a more complex influence on the pattern of stage and discharge at this gage, as will be seen below.

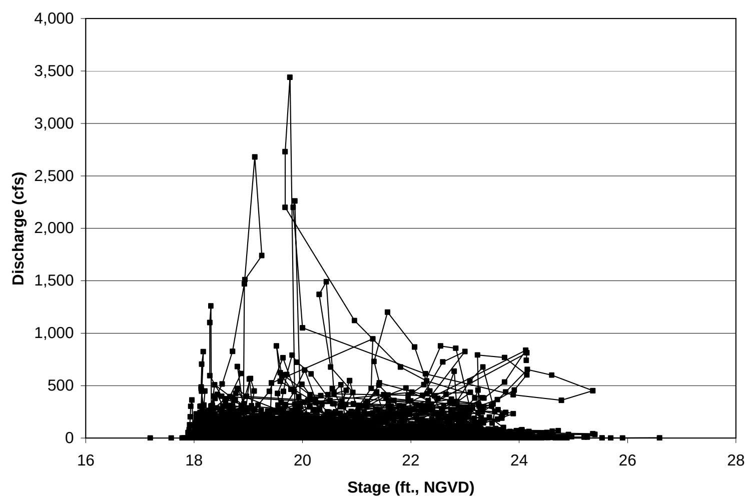


Figure 3-25 Relationship of stage and discharge in data from the Tenmile Creek gage.

Figure 3-25 depicts the relationship between stage and discharge in the Tenmile Creek data. The stage-discharge pattern can be decomposed into two types of events: tropical storm-hurricane responses and small rainfall event responses.

Figure 3-26 illustrates a tropical storm-hurricane response. Segment A represents a rapid rise in discharge with a drop in stage. Hurricane Dora went inland, to the northeast, relative to the Tenmile Creek gage, so offshore winds would have increased discharge while blowing water offshore, thereby lowering the stage. After the offshore wind set-up abated and the storm center passed, an onshore wind and flooding occurred (Segment B).

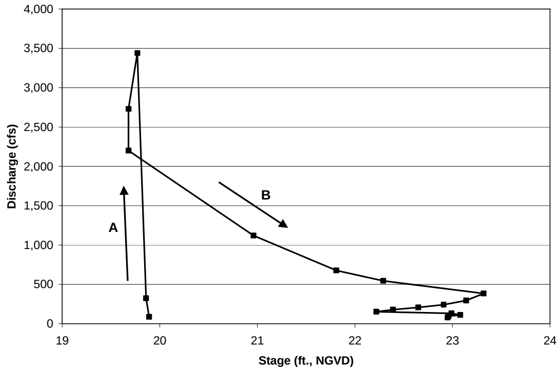


Figure 3-26 Relationship of stage and discharge during the flood of September 9-26, 1964 (Hurricane Dora).

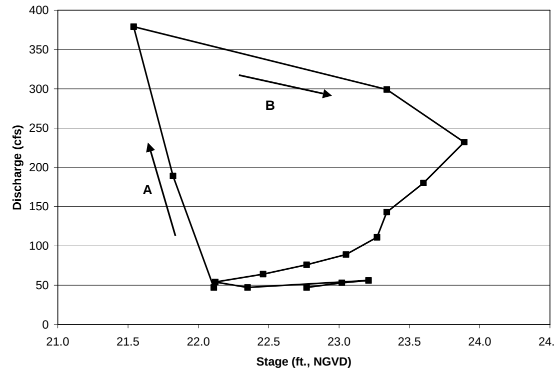


Figure 3-27 Relationship of stage and discharge during a rainfall event from March 6-22, 1987.

A more normal rainfall event is reflected in the stage-discharge data from March 6 – 22, 1987, data (Figure 3-27). Here, an offshore wind apparently lowered stage while rainfall caused an increase in discharge (Segment A). After the offshore wind abated, inundation of the floodplain was accompanied by a decrease in discharge and increase in stage. The final segment (unlabeled) represents the final draining of the floodplain accompanied by reductions in both discharge and stage.

A baseline flow duration curve can be created for the discharge data from the Tenmile Creek gage (Figure 3-28). Table 3-9 presents the summary statistics for this flow duration curve as well as monthly flow statistics.

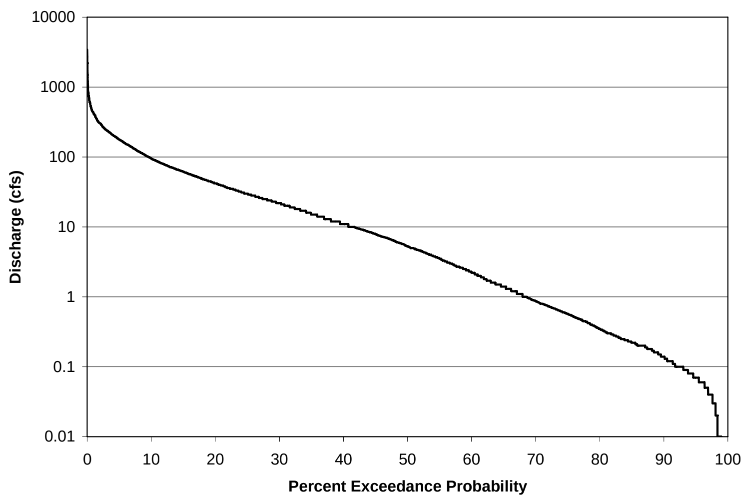


Figure 3-28 Baseline (historic) flow duration curve for discharge at the Tenmile Creek near Lebanon Station gage (Gage 02314200).

Table 3-9 Annual and monthly discharge statistics for data from Tenmile Creek at Lebanon Station. (n = 12,790)

Period	**Minimum** (cfs)	**0.25 Exceedance Probability** (cfs)	**0.50 Exceedance Probability** (cfs)	**0.75 Exceedance Probability** (cfs)	**Maximum** (cfs)
Annual	0.00	0.53	5	29	3,440
January	0.12	1.4	8.6	31	946
February	0.03	3.7	16	48	1,260
March	0.04	2.2	15	51	1,490
April	0.01	0.36	1.6	13.75	637
May	0.00	0.08	0.2	0.72	230
June	0.00	0.08	0.47	6.18	824
July	0.00	0.47	5.5	37	2,260
August	0.00	9.2	33	110	1,200
September	0.00	9.03	23	72.75	3,440
October	0.00	0.61	4.9	23	638
November	0.00	0.25	1.6	6.5	475
December	0.08	0.48	2.6	13	708

Table 3-9 and Figure 3-29 reflect the seasonality in rainfall in the study area. Highest median monthly discharge is in August and September, rainy season months, and lowest is in May and June, the end of the dry season.

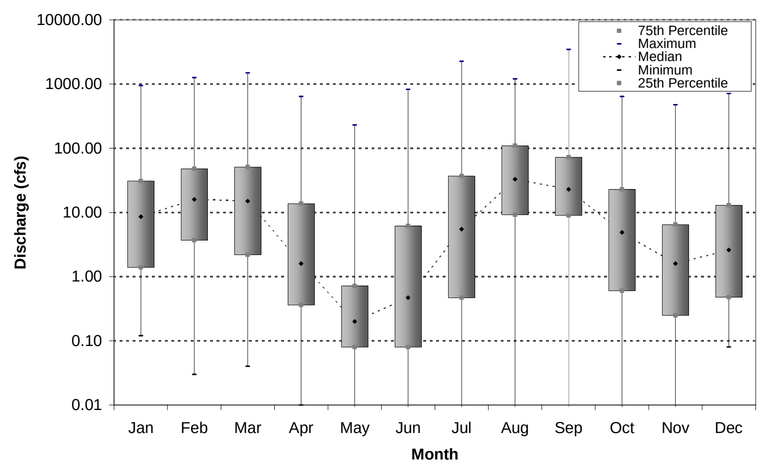


Figure 3-29 Box and whisker diagram showing seasonal variability in discharge at the Tenmile Creek gage at Lebanon Station.

TAB 4

4.0 Ecological Analyses

Hydrologic conditions are among the principal physical forces that influence the function of stream ecosystems (Poff et al., 1997; Poff and Ward, 1989). Flow influences ecological integrity directly (Poff and Alan, 1995), or indirectly via other factors, such as water quality, physical habitats, etc. (Schlosser, 1991; Poff et al., 1997). The MFL proposed in this document is oriented towards protection of estuarine and tidal habitats of the Waccasassa River system, with the assumption that adequate flow to the lower portion of the river also provides adequate flow for the non-tidal portion of the river.

This section characterizes the ecology of the Waccasassa River. The hydrologic description provided in Section 3 serves as the framework which structures the ecological communities of the river, including those in the river channel, adjacent floodplain and bay. As previously stated, the Suwannee region (which includes the Waccasassa) is a significant bio-geographic transition zone in Florida, with many species of flora and fauna reaching their southernmost limits of distribution in the U.S. in the Suwannee region. A number of plant species reach the southern or northern limits of their distribution in the southeastern U.S. in the Suwannee region (Clewell, 1985; Abbott and Judd, 1998) and over half of the native fresh-water fishes found in Florida river systems occur only in or west of the Suwannee (Bass and Cox, 1985; Bass, 1991).

4.1 General Description

4.1.1 Physical Setting

The Waccasassa River is a relatively undeveloped, scenic river, with several interesting characteristics that add to its ecological importance. The river begins in the swamps of the Waccasassa Flats, which is a complex of swamps and pine flatwoods located in northern and central Gilchrist County (Figure 1-1). The Flats area is characterized by low substrate permeability, which forms swampy areas due to low groundwater recharge and pooled rainfall. The area has a slight gradient that directs runoff towards the margins of the Flats where several rivers and streams originate. However, only a small portion of surface flow from the Flats contributes to flow in the Waccasassa River; most of the surface flow from the Flats flows eastward and westward into large sinkholes and closed depressions (i.e., note the parallel lines of lakes that border the Flats in Figure 1-1).

The Waccasassa River becomes a recognizable stream in southern Gilchrist County. Most of the river flows through forested and swampy areas, including a broad expanse of bottomland hardwood swamps in the mid-section of the river. The channel of the river becomes well defined where the Little Waccasassa joins the Waccasassa River (Figure 1-1). Levy Blue Spring discharges into the Little Waccasassa approximately 1,100 feet upstream from the confluence with the Waccasassa (Figure 1-1). Because of the close proximity, many consider Levy Blue Spring to be the head of the Waccasassa River. South of the confluence with the Little Waccasassa, the Waccasassa River flows through a region known as Devils Hammock and a portion of the river discharge is distributed to Otter Creek (Figure 1-1) during high flow episodes. Further downstream, near Gulf Hammock, the Waccasassa merges with the Wekiva River, which receives flow from Wekiva Springs (Figure 1-1). The river also receives flow from Otter Creek, Cow Creek, Magee Branch, and Ten Mile Creek before discharging into Waccasassa Bay (Figure 1-1).

Waccasassa Bay is a shallow embayment extending into the Gulf of Mexico between Cedar Key and the Withlacoochee River. The bay receives discharge from the Waccasassa River, with contributions from Otter Creek and Ten Mile Creek. The bay is an important component of the estuary that supports sport and commercial fisheries, which rely heavily on the ecological functions of the tidally influenced marshes and creeks associated with the river.

4.2 Water Quality

Water quality in the Waccasassa River is an issue in terms of both the impact of surfacewater interactions with the groundwater system and the impact of surfacewater quality on aquatic habitat and associated fauna, both in the river and bay. Available water-quality data were discussed in a previous report (WRA, 2005). Water-quality data were available from one District station located on the river near Gulf Hammock at State Road 326 (WAC010) which has been monitored monthly (during the day) since 1989 (Figure 4-1). Additional water-quality data were available for a second station (WAC005) for an abbreviated period of record (1994-1995). Parameters sampled at the long term station include: alkalinity, chlorophyll, color, conductivity, nitrate+nitrite (NOx) species, orthophosphate, pH, temperature, total Kjeldahl nitrogen (TKN), total nitrogen (TN), total organic carbon (TOC), total phosphorus (TP), total suspended solids (TSS), and turbidity.

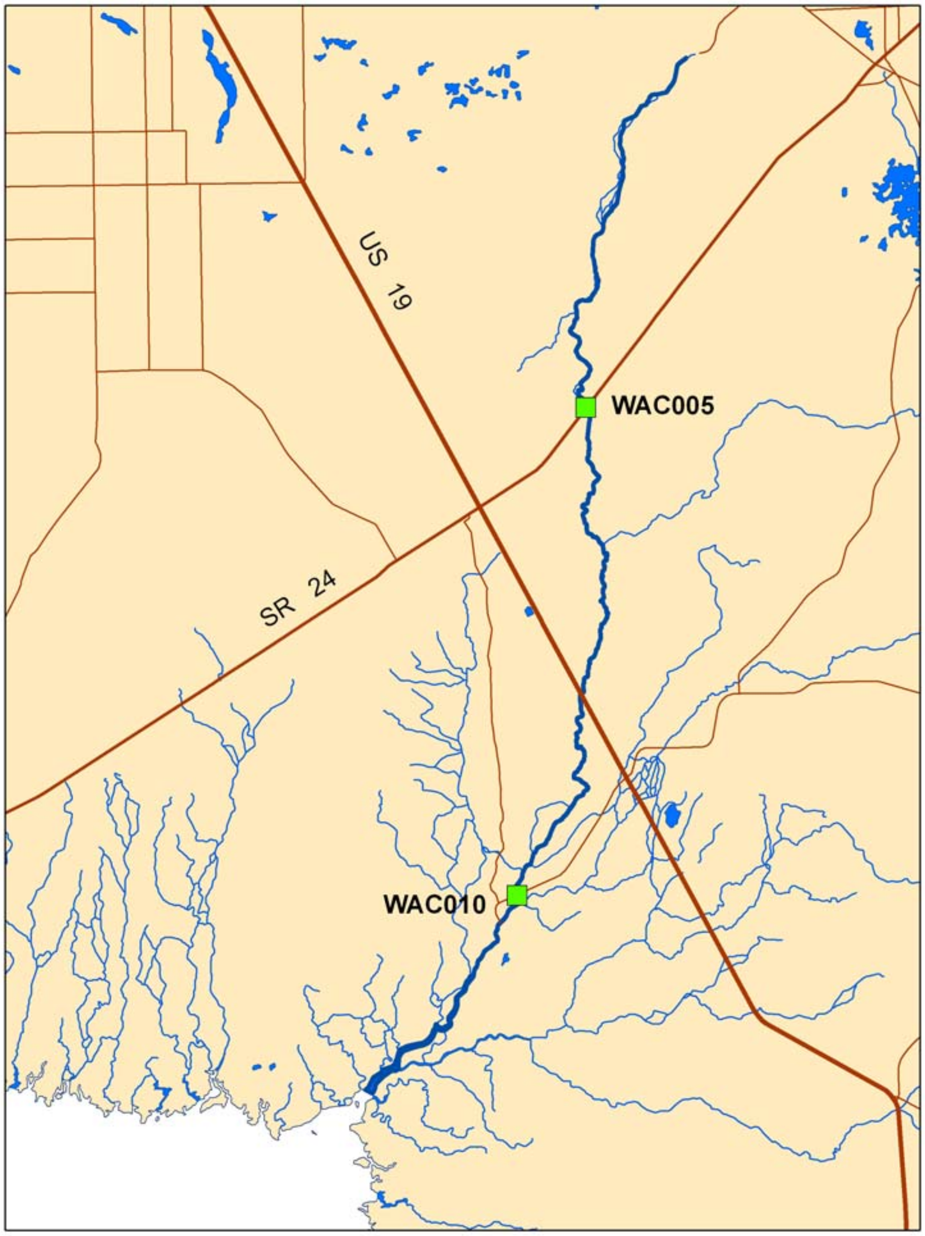


Figure 4-1 Locator map of the Waccasassa River, showing the main water quality and biology station (WAC010) and an additional station (WAC050) with limited period of record, maintained by the Suwannee River Water Management District.

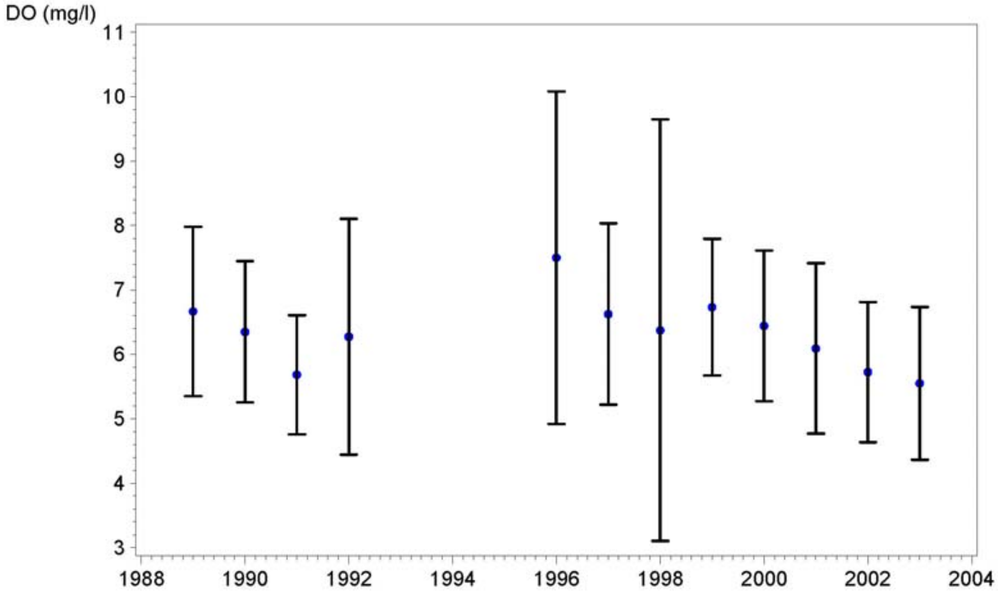


Figure 4-2 Mean annual dissolved oxygen (mg/l), with 95% confidence limits, for the Waccasassa River near Gulf Hammock in the Suwannee River Water Management District. (Source: Janicki Environmental, Inc., 2004).

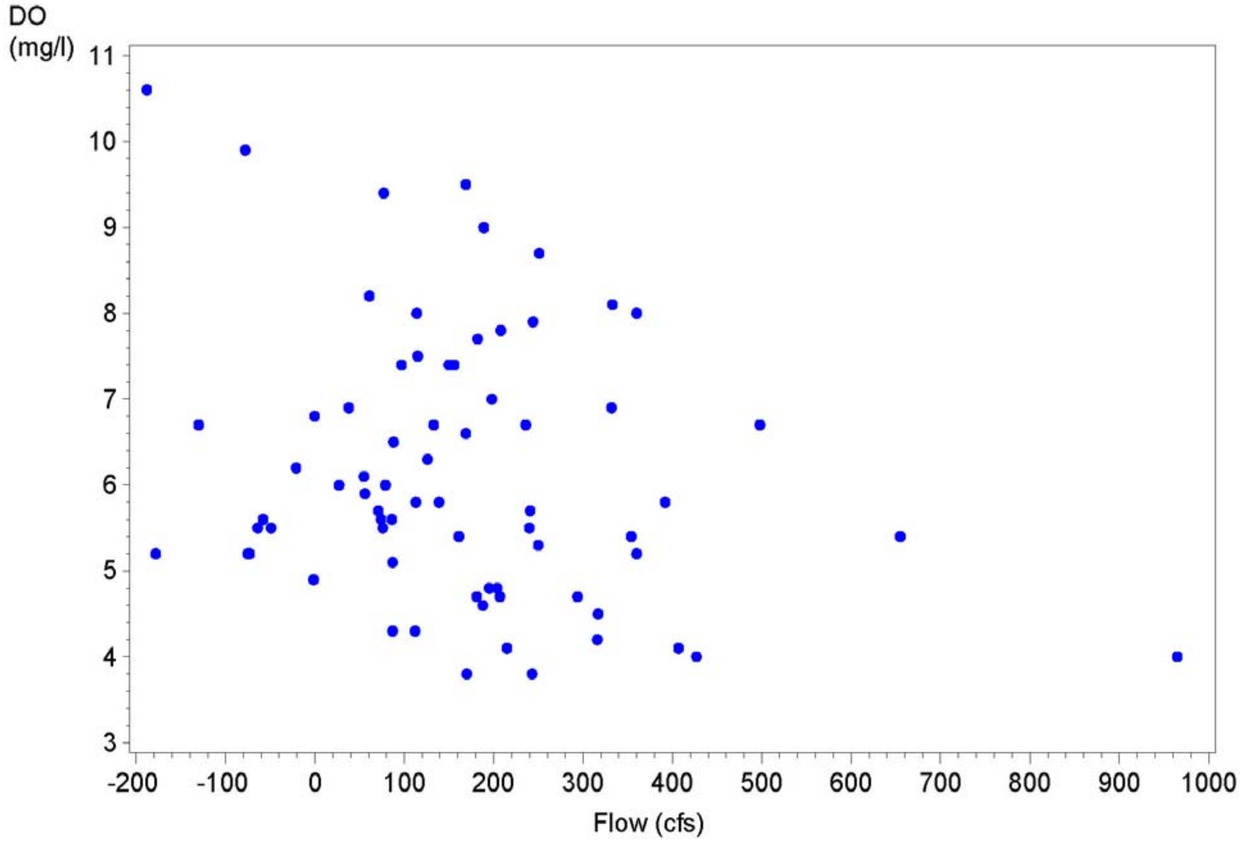


Figure 4-3 The relationship between dissolved oxygen at Suwannee River Water Management District station WAC010 and flow in the Waccasassa River near Gulf Hammock between 1989-2003.

Mean annual dissolved oxygen (DO) ranged from 5.5 to 7.5 mg/L in the Waccasassa River for the period of record (Figure 4-2). Plots for additional parameters are located in Appendix D. A scatter plot of DO as a function of flow showed the full range of DO values occurred at low to moderate flows (Figure 4-3). DO values below 5 mg/L occurred over the full range of flows, from 0-1000 cfs (Figure 4-3).

Water quality data were also available for the lower portion of the Waccasassa River/Bay from a study collected by Mote Marine Lab for the Southwest Florida Water Management District in 1984-1985 (Culter, 1986; Dixon, 1986). Monthly samples were conducted during the first year of the study and bimonthly samples during the second year. It should be noted that several major events occurred over the course of the study: a statewide drought between November 1984 and July 1985, subsequent drought recovery, and a major hurricane (i.e., Hurricane Elena). Parameters collected by the Mote study included salinity, dissolved oxygen, pH, and temperature (all at 1 meter depth intervals). Nitrogen, phosphorus, pigments, color, turbidity, suspended load and light penetration were also recorded at selected stations. Sediments were also sampled by Mote and provide grain size distribution and percent combustible organics.

Results indicated that the tidal portion of the Waccasassa River had lower DO values (i.e., percent saturation and absolute concentrations) than the other rivers investigated during the same study (Withlacoochee, Crystal, and Weeki Wachee Rivers, and Aripeka/Hammock Creek). Mean DO concentrations in the lower Waccasassa River ranged from 4.9 to 7.0 mg/L (Dixon, 1986). Fresh-water flow (and the associated organic input) and high color were hypothesized to be related to depressed DO concentrations in the lower portion of the river. It was suggested that oxygen production by submerged aquatic vegetation or phytoplankton could not counteract depletions due to oxygen-demanding substances (Dixon, 1986). Average color on the Waccasassa ranged from 27 to 46 platinum cobalt units (PCU), which was significantly higher than other rivers in this study (with the exception of the Withlacoochee). Even stations in the bay were determined to have water that was high in color, and Dixon (1986) stated that the Waccasassa generally had the highest concentrations of organics of any of the estuaries in the study. Because Waccasassa Bay is so shallow, it was expected that wind-driven currents would increase suspended solids and turbidity. Waccasassa Bay had the highest values for suspended-solids load (14 mg/L) and turbidity (10 NTU) of the rivers studied (Dixon, 1986).

The Waccasassa River had the highest average levels of phosphorus and nitrogen species analyzed, with the exception of nitrate+nitrite nitrogen (Dixon, 1986). Inverse relationships between inorganic (nitrate+nitrite nitrogen) and organic nitrogen species (TKN) were observed as related to salinity (Dixon, 1986). Inorganic species (i.e., ammonia, nitrate+nitrite nitrogen, and orthophosphate) decreased from upstream to downstream. Oxidized forms of nitrogen were high upstream, indicating variable inputs, but decreased to constant and low levels offshore. Mean values for nitrate+nitrite nitrogen ranged from 0.064 to 0.004 mg/L/N at the most downstream sampling location (Dixon, 1986). Orthophosphate means ranged from 0.032 to 0.018 mg/L and ammonia nitrogen (ionized and unionized forms) means ranged from 0.027 to 0.012 mg/L throughout the river.

Both orthophosphate and ammonia exhibited seasonal patterns of summer maxima and were significantly related to temperature (Dixon, 1986). Total phosphorus means ranged from 0.09 to 0.12 mg/L/P and TKN means ranged from 0.51 to 0.93 mg/L/N; variations in concentration of both Total P and TKN were similar to each other and to variations exhibited in suspended load (Dixon, 1986). Summer maxima for the organic fractions of Total P and TKN were observed and seasonal variations were attributed to salinity. Both organic N and P were lowest at the upstream station (Dixon, 1986).

Additionally, water-quality data available from EPA STORET for the Waccasassa River watershed were analyzed by Dixon (1997) in a report on data inventory and trend analysis for the Florida Springs Coast. Based on maps provided in the report, all of the stations were in the upper watershed, as opposed to being in the lower river. Five stations were determined to have sufficient data for analysis and these consisted of three stations maintained by the USGS and two by SRWMD. Based on the variable time periods represented by these data, no overriding trends were reported. By station, it appeared that decreasing ammonium-nitrogen and total phosphorus were observed between 1975-1995 at a station near the confluence of the Waccasassa River and Otter Creek (Dixon, 1997). Another station, near the Waccasassa River at SR 326 showed increasing dissolved oxygen and decreasing ammonium-nitrogen between 1987-1994. Another station near Gulf Hammock and US 19 showed decreasing pH, increasing color, and possibly decreasing nitrate+nitrite-nitrogen, nitrate-nitrogen, and ammonium nitrogen between 1989-1996 (Dixon, 1997).

4.2.1 Springs

The springs of the Waccasassa River were previously described in Sections 2 and 3. Springs are important components of riverine systems both for their contribution to base flow of the river and for providing additional habitat for spring flora and fauna to occupy. In addition to providing ecological functions, springs are widely used for recreation and, as such, coliform levels in the springs may represent a human health concern. Because no data are available for Blue Spring, data on Lithia Spring (which discharges to the Alafia River in Hillsborough County, Florida) were used for general comparison purposes on fecal coliform levels and swimming standards due to its heavy use as a recreational spring. Lithia Springs is not intended to be used as proxy for Levy Blue with respect to coliform levels, but rather an general indicator as to the extent swimming activities have on the health of a spring.

A biological assessment of Lithia Springs was conducted in order to determine the effects of nutrient loading on the spring system (Berg et al., 2003). Included in this assessment was an evaluation of coliform levels. In Lithia Springs, the coliform community was composed of *Escherichia coli, Edwarsiella tarda, Enterobacter cloacae*, and *Klebsiella pnemoniae*. Numbers of each type of bacteria were low at each station sampled, with total coliform counts ranging from 45 per 100 mL of sample to a high of 132 per 100 mL of sample (Berg et al., 2003). It was concluded that coliform counts in Lithia Springs were well below the daily allowed maximum of 800 per 100 mL of sample, and below the allowed average value of 200 per 100 mL of sample, which are considered the levels of bacteria that pose a threat to the human population (Chapter 64E-9.013 F.A.C.). Additionally, *Enterococci* were detected at levels ranging from <1 to 3 per 100 mL in Lithia Springs, which is well below the limit of 61 per 100 mL of sample (Chapter 64E-9.013 F.A.C.). These data indicate the spring is suitable for recreation, but levels were higher than those acceptable for human consumption (Berg, et al., 2003). Additionally, all areas established as public bathing areas must have a minimum flow through of 500 gallon per anticipated bather per 24 hours, unless the surface area of the body of water is 2 acres or greater (Chapter 64E-9.013 F.A.C.).

4.3 Riparian Communities

The riparian wetland vegetation has been characterized and classified by the SRWMD 1994-1995 Land Use and Cover Project and from the National Wetlands Inventory (NWI). Additionally, information on vegetative communities in the Waccasassa River were summarized from existing reports and field notes within the area, and literature from comparable areas (i.e., the Lower Suwannee River).

The Land Use and Cover Project was funded as part of the SRWMD's Surface Water Improvement and Management (SWIM) program in efforts to better understand the water resources and to monitor changes in land use and cover over time within the SWIM waterbodies (SRWMD, 1998). The land use and cover data were photo-interpreted from 1994-1995 National Aerial Photography Program (NAPP) 1:40,000 color infrared photography. Photo interpretation was accomplished using United States Geological Survey 7.5' quadrangle base maps (SRWMD, 1998). Data were classified based on a modified Florida Land Use Cover and Forms Classification System (FLUCFCS), originally established by the Florida Department of Transportation. Similar cover types were grouped into polygons using mylar overlay and then digitized into ArcInfo®. Ground truthing was performed and overall accuracy was determined to be 85% (SRWMD, 1998).

The National Wetlands Inventory (NWI) is a program established under the United States Fish and Wildlife Service with the purpose of characterizing the extent and status of the Nation's wetland, deepwater, and other wildlife habitats. The goals of the NWI are to classify and map the nation's wetlands and to periodically assess status and trends (USFWS, 2002). NWI maps contain information on location and type (classification) of wetlands and deepwater habitats (stream, lakes, and estuaries). NWI information is based on the interpretation of high-altitude aerial photographs, with a minimum required mapping resolution of 2 acres. Additionally, it should be noted that the mapped area is the approximate location and size of the wetland, relative to geographic features (e.g., roads) and annual and seasonal variation (e.g. in dry years wetland extent will be limited compared to wetter years; same for dry vs. wet seasons within a year) at the time the aerial photos were taken. Accuracy is limited to 30-50 feet (USFWS, 2002).

4.3.1 Description of Available Riparian Information

Studies of the Waccasassa River

In a floristic inventory of the Waccasassa Bay State Preserve by Abbott and Judd (1998), 72 species were reported at or approaching their northern or southern distributional limits; 18 of these species were reported as having disjunct distributions or very restricted ranges in Florida, with 15 species being endemic or near-endemic. Five natural communities, in addition to ruderal areas, were identified based on field observations using vegetation categories established by the Florida Natural Areas Inventory and the Florida Department of Natural Resources (FNAI and FDNR, 1990). The five communities consisted of tidal marsh, coastal hydric hammock, fresh-water pools, basin swamp, and mesic to scrubby flatwoods (Abott and Judd, 1998). In most areas, these communities are scattered in a mosaic of poorly defined, often intermixed patches (Abbott and Judd, 1998). Ruderal areas were reported as "weedy" with signs of human disturbance and non-indigenous species and were reported as possibly occurring within any of the above-mentioned communities (Abbott and Judd, 1998).

A vegetation survey of coastal estuaries between the Aripeka and the Waccasassa River was conducted by Mote Marine Laboratory and Mangrove Systems Inc. for the Southwest Florida Management District (Mote and Mangrove, 1986). A number of transects were placed along the river and from the mouth, upstream to rkm 9. It should be noted that that the river kilometer system developed for this project does not exactly match the system used by Mote and Mangrove (1986), as different points were chosen as the river mouth (zero point). To correct for this difference it was necessary to convert their river mile system to kilometers and then subtract 0.56 to get the rkm value that corresponds to our system. Essentially the location designated as the river mouth in this report was -0.56 kilometers from the location used by Mote and Mangrove (1986) River kilometers are used throughout this report and original river miles described by Mote and Mangrove (1986) have been converted and replaced by the rkm values that correspond to the rest of the analyses contained in this report.

The most upstream transects were vegetated by species characteristic of forested floodplains; the banks of the river are steeper here than further downstream and banks on both sides were dominated by forested floodplain species downstream until rkm 7.6 (Mote and Mangrove, 1986). Highest diversity was reported in the most upstream transects consisting of freshwater forested shoreline (Mote and Mangrove, 1986). Between rkm 7.6 and rkm 4.6, patches of tidal fresh-water marsh or oligohaline marsh, dominated by sawgrass (*Cladium jamaicence)*, wild rice *(Zizaniopsis miliacea)*, arrowhead (*Sagitarria lancifolia)*, and swamp lily (*Crinum americanum)* were found (Mote and Mangrove, 1986) (Figure 4-4). By rkm 4.6, marsh vegetation replaces the forested shoreline completely (Mote and Mangrove, 1986). Natural levees line the shore along Strafford Island and support the growth of small trees and shrubs including red cedar *(Juniperus siliciola)* and spanish bayonet (*Yucca aloifia)* (Figure 4-4). The most dramatic transition zone appeared to be near rkm 4.2, adjacent to Strafford Island where the last stance of fresh-water species still occurred, before being replaced entirely by salt-tolerant species further downstream (Mote and Mangrove, 1986).

The lowest diversity occurred, as expected, in the often monotypic saltmarsh located at the furthest extent downstream (Mote and Mangrove, 1986). Polyhaline conditions were reported from approximately rkm 2.7 down to the mouth of the river (rkm -0.56) (Figure 4-4). This was evidenced by the prevalence of saltmarsh vegetation, namely saltmarsh cordgrass (*Spartina alterniflora)*. A few hammocks were reported adjacent to the shoreline with saltmarsh. These hammocks consisted of cabbage palm (*Sabal palmetto)* and red cedar. Downstream of the confluence with Cow Creek, the marsh was dominated by saltmarsh cordgrass, with black needlerush *(Juncus roemerianus)* and occasionally *Iva spp.* occurring in the landward marsh (Mote and Mangrove, 1986).

Field notes were available from the Waccasassa Estuary Salinity Monitoring Network from a trip on October 26, 2004 and reported by Giambrone and Mattson (2004). The healthiest tidal swamp, which was characterized by cabbage palm, sweet bay *(Magnolia virginiana*), bald cypress *(Taxodium distichum*), slash pine *(Pinus ellioti),* swamp black gum (*Nyssa sylvatica* var. *biflora*) and wax myrtle *(Myrica cerifera)*, occurred at rkm 7.27 (SRWMD station WR000). Some tree dieback was reported at this site. Between rkm 6.35 (SRWMD station WR050) and rkm 5.5 (WR100) the tidal swamp was reported as having some tree dieback, consisting mostly of stressed cypress or dead cypress, a thinning canopy and the presence of saw grass in the understory was noted, indicating a transitional area of forest-marsh conversion. Near rkm 4.8 (WR141), at the upstream end of Strafford Island, fair quality tidal swamp with cabbage palm, red cedar and sweet bay was reported, along with an understory of sawgrass and the first presence of black needlerush along the riverbank. This area was where the “tree line” occurred. Brackish/mixed tidal marsh, characterized by black needlerush, sawgrass, sparse saltmarsh cordgrass, and hummocks of cabbage palm, red cedar, *Baccharis spp.* and *Iva spp.* were reported at rkm 4.29 (WR192). Saltmarsh, consisting of saltmarsh cordgrass and black needlerush were reported, along with sparse occurrence of trees and shrubs in the marsh at rkm 3.97 (WR191). Near the downstream end of Strafford Island at rkm 2.98 (WR241), down to

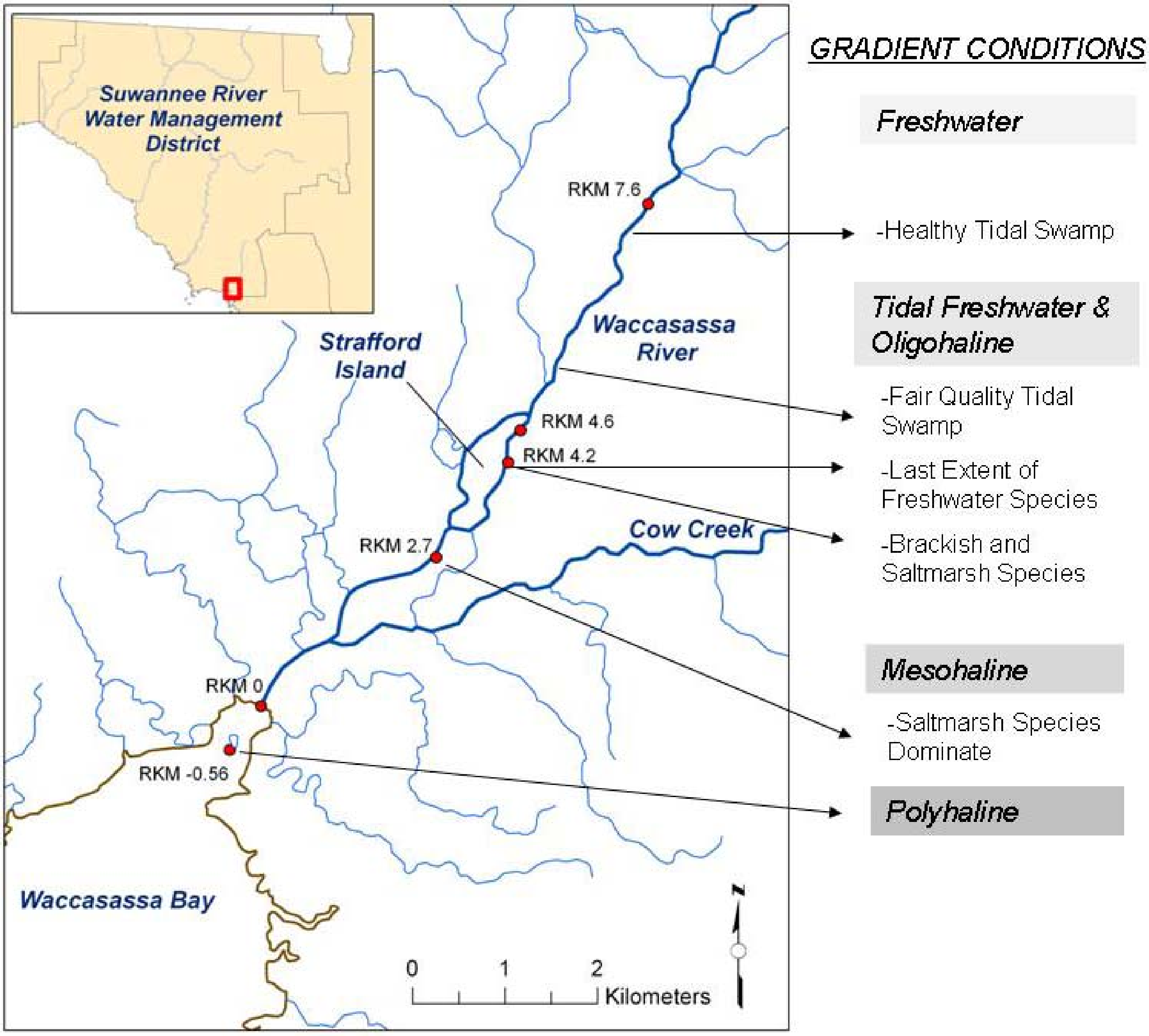


Figure 4-4 Map showing the lower portion of the Waccasassa River and Waccasassa Bay. Strafford Island is a prominent feature in the middle of the river channel, between river kilometers 3.0 and 4.8. River kilometers associated with important vegetation and/or salinity gradients are labeled.

the mouth of the river, marsh consisting of saltmarsh cordgrass and black needlerush dominate with scattered hummocks of cabbage palm (Giambrone and Mattson, 2004).

Relevant Studies of the Lower Suwannee River

In the nearby Lower Suwannee River, Light et al. (2002) identified thirteen distinct, wetland forest community types in three major reaches of the river. A total of 77 woody plant species (trees, shrubs and woody vines) were identified in the canopy and sub-canopy of these thirteen forest types. Nine of these forest types are associated with the riverine portion of the system

('Riverine' and 'Upper Tidal' reaches). The remaining four forest types ('Lower Tidal' reach) are considered part of the estuary. Eight of their 13 wetland forest types had a total canopy and sub-canopy plant species richness of > 30 tree taxa. This species richness was among the highest compared to tree diversity in other southeastern U.S. floodplain forests (Light et al., 2002). Two hundred eighty-one herbaceous and woody groundcover species, with many new county records, were found in the thirteen forest types in a follow-up study (Darst et al., 2002). These results indicate that plant community diversity is exceptional in the lower Suwannee floodplain forests.

A study on tidal-marsh vegetation was conducted on the Lower Suwannee River by Clewell et al. (1999). In summary, black needlerush dominated saline areas and sawgrass inhabited fresher areas and formed a transition between needlerush marsh and tidal river swamp. The vegetation of the levees differed from the vegetation of the intertidal marsh. Saltmarsh cordgrass and black needlerush dominated mesohaline riverbanks and sawgrass and needlerush occurred on the oligohaline riverbanks. Riverbank vegetation was directly influenced by fresh-water flow from the river, with opportunistic freshwater species extending downstream during periods of high discharge. Interior marshes were isolated from the river. Although river salinity did not correlate well with the distribution of riverbank species, a significant correlation was calculated between maximum river salinity and the abundance sawgrass and needlerush at intervals along the riverbank (Clewell et al., 1999).

National Wetlands Inventory and Land Use Coverages

Based on coverages available from the NWI, general descriptions of the habitat type and water regimes present on the Waccasassa River are available. Three types of habitats were recorded by the NWI, listed in ascending order of acreage: intertidal estuarine (4771 acres), forested palustrine (11,937 acres), and uplands (13,882 acres) (Figure 4-5). Acreage estimates were determined for the area within the 1-mile buffer shown on Figure 4-5, since floodplain coverages were not available for the Waccasassa. Near the mouth of the river, from rkm 0 to 5, intertidal estuarine habitat dominates. Above rkm 5, extending upstream past rkm 40 is forested palustrine and upland habitat. Forested palustrine habitat occurs along the river where flooding takes place, as opposed to uplands, which require dry areas. A larger tract of forested palustrine habitat can be seen adjacent to the riverbank (particularly between rkm 30 and 40), which correlates with the semi-permanently and seasonally flooded areas. Within the one mile buffer, the water regime is distributed as follows, in order of ascending acreage: temporarily flooded (974 acres), seasonally flooded (5,717 acres), semi-permanently flooded (5,795 acres) (Figure 4-6).

The NWI categories for water regimes that occur in the floodplains of the Waccasassa are: temporarily flooded, seasonally flooded, semi-permanently flooded. These categories are defined as (Figure 4-6):

Temporarily flooded: surfacewater is present or soil is saturated for brief periods during the growing season, but the water table usually lies well below the soil surface for most of the season. A typical frequency of flooding is 11 to 50 years out of 100; typical duration is 2-12.5 percent of the growing season.

Seasonally flooded: surfacewater or saturated soil is present for extended periods, especially early in the growing season, but is absent by the end of the season in most years. Flood frequency ranges from 51 to 100 years per 100 years; flood duration is typically 12.5-25 percent of the growing season.

Semi-permanently flooded: surfacewater or soil saturation persists for a major portion of the growing season in most years. Flooding frequency ranges from 51 to 100 years per 100 years; flooding duration typically exceeds 25 percent of the growing season.

Waccasassa River

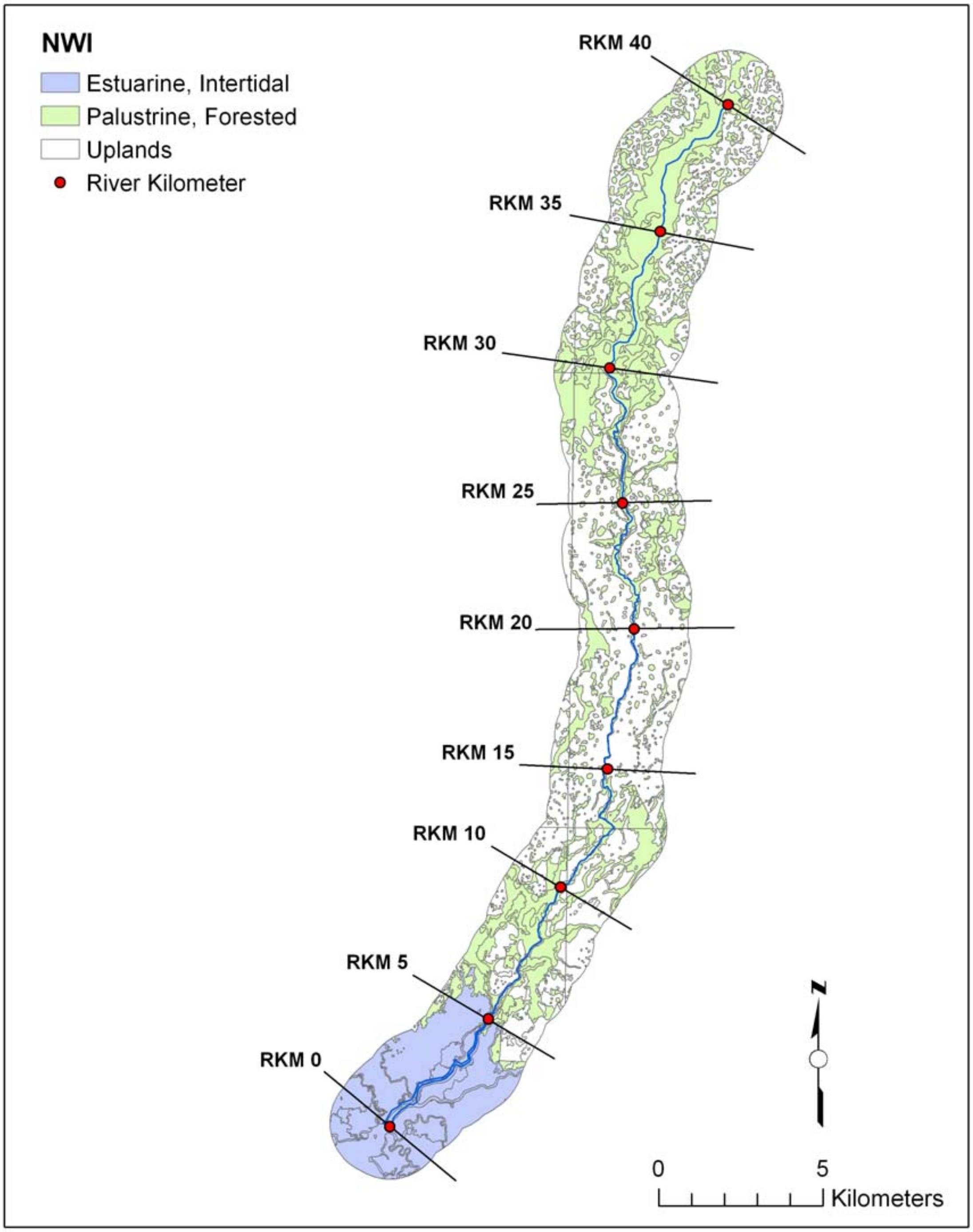


Figure 4-5 National Wetlands Inventory habitat designations based on Cowardin et al. (1979). Area shown represents a one-mile buffer along the Waccasassa River.

Waccasassa River

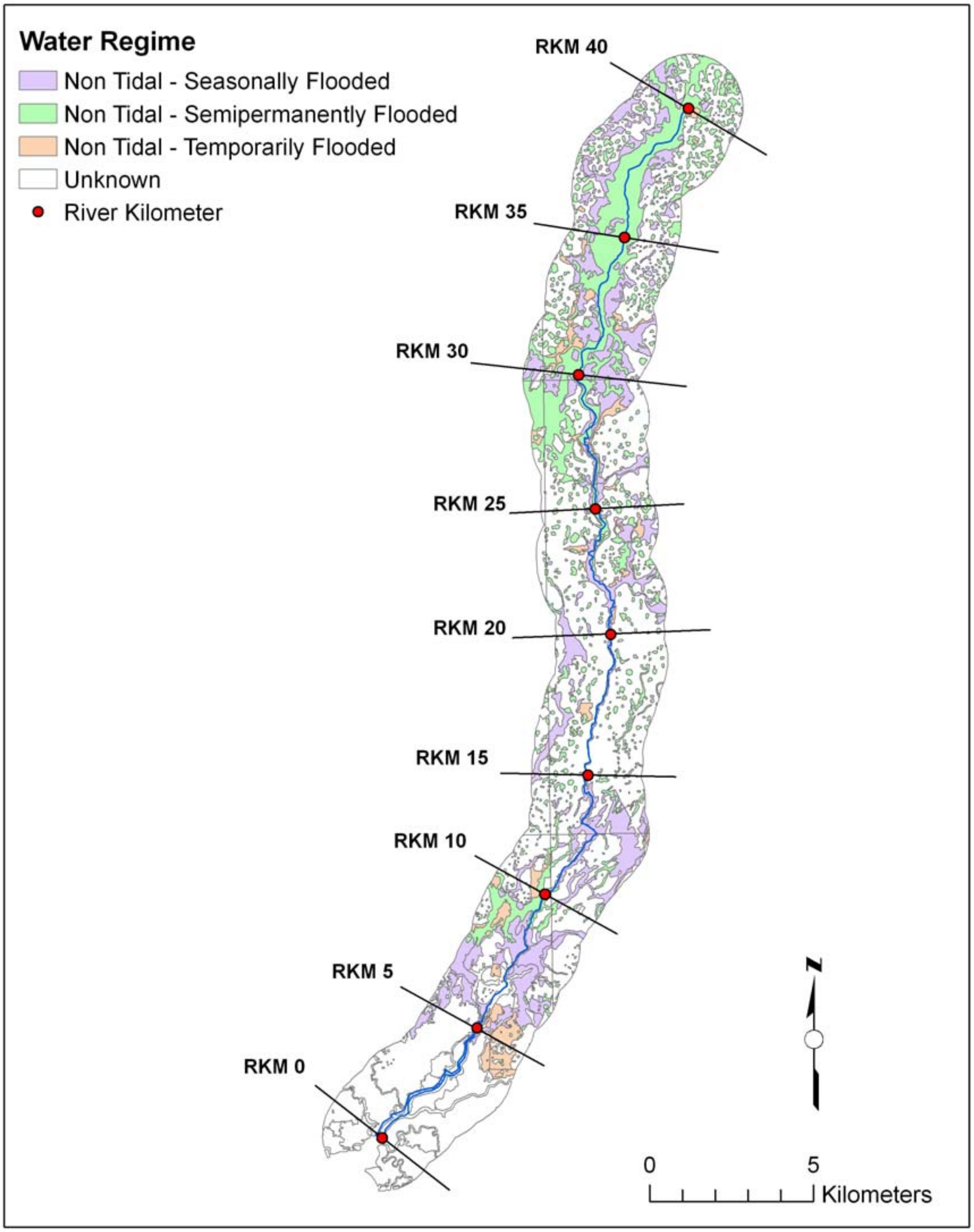


Figure 4-6 National Wetlands Inventory water regime designations based on Cowardin et al. (1979). Area shown represents a one-mile buffer along the Waccasassa River.

Waccasassa River

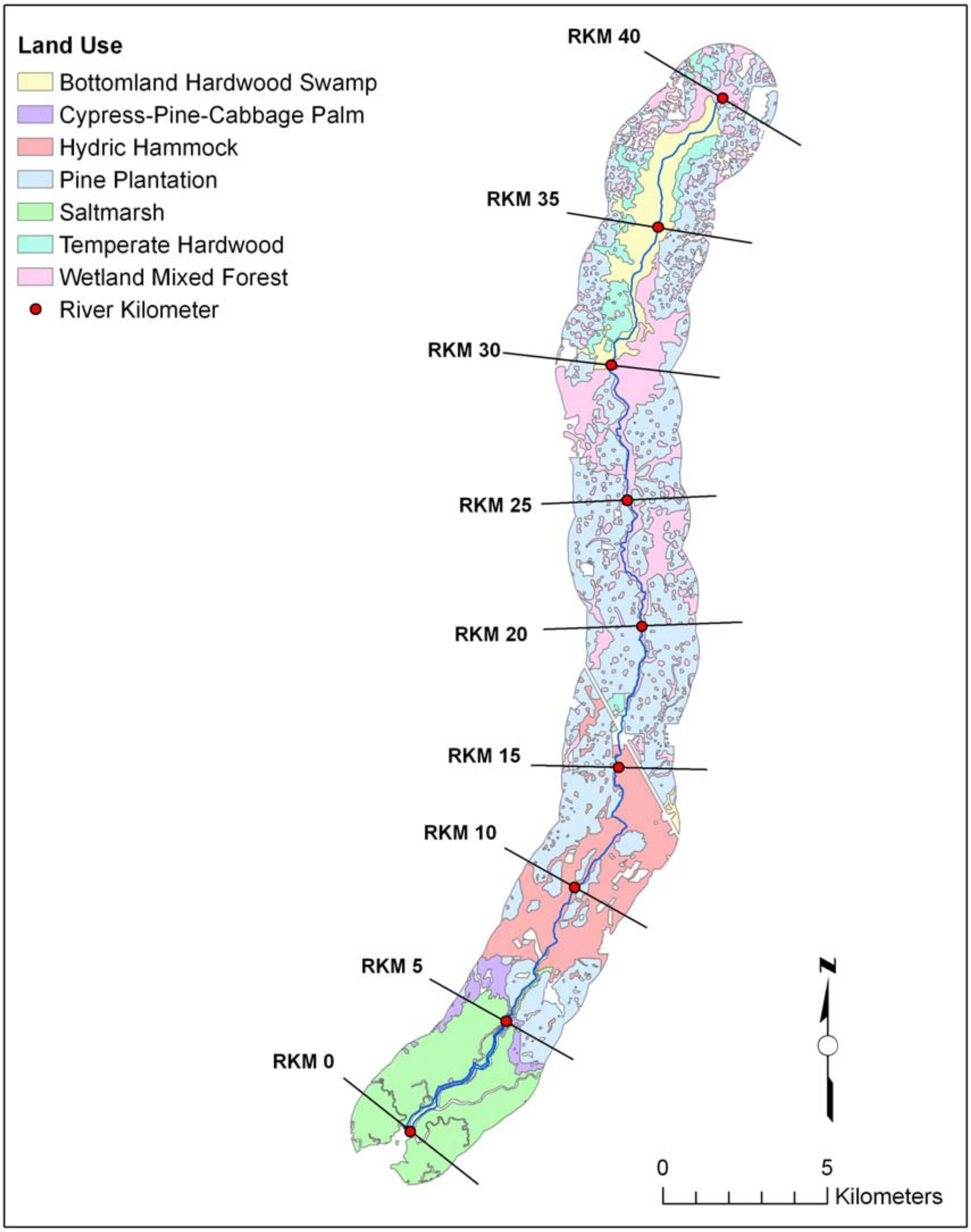


Figure 4-7 1995 Land use data provided by SRWMD. Area shown represents a one-mile buffer along the Waccasassa River.

More specific information on vegetation communities was derived from SRWMD 1995 land use data (Figure 4-7) and include the following community types listed in ascending order of acreage: cypress-pine-cabbage palm (572 acres), temperate hardwood (1,030 acres), bottomland hardwood swamp (1,990 acres), hydric hammock (3,640 acres), saltmarsh (4,069 acres), wetland mixed forest (5,202 acres), and pine plantation (12,305 acres). Acreage estimates were determined for the area shown within the 1-mile buffer shown on Figure 4-7, since floodplain coverages were not available for the Waccasassa. Saltmarsh habitat dominates near the mouth of the river, between rkm 0 and 5. Directly upstream of the marsh habitat is a small extent of cypress and pine trees, as well as cabbage palm. Managed pine plantations also occur upstream of the marsh habitat. An expanse of hydric hammock occurs between rkm 7 and 16. Between rkm 15 and 30 pine plantation and mixed wetland forests occur. At approximately rkm 30 and above, bottomland hardwood swamps occur adjacent to the river, in what correlates to the most extensive area of semi-permanently flooded habitat on the river based on the NWI water regime coverage. Surrounding the bottomland hardwood swamps are temperate hardwood forests and wetland mixed forests.

4.4 Synthesis of Riparian Information and Community Descriptions

Descriptive information on the vegetation communities located along the Waccasassa River were largely derived from the SRWMD 1995 Land Use data, supplemented by other sources as needed, particularly in describing the tidally influenced portion of the river. These data provided the most information on species composition. Non-tidal forested communities are described first, followed by tidally influenced forests/swamps, then tidal freshwater, oligohaline and saltmarshes. Following each tidally influenced community are figures summarizing the available information on salinity ranges for the likely dominant species.

4.4.1 Bottomland Hardwood Forest/Swamp

Wetland forests include a diverse assortment of hydric hardwoods and are typically found along the riverbank in areas of river overflow. Generally they occur on rich alluvial silt- and clay-rich sediments deposited along rivers and are characterized by an overstory of water hickory (*Carya aquatica*), overcup oak (*Quercus lyrata*), swamp chestnut oak (*Quercus michauxii*), river birch (*Betula nigra*), American sycamore (*Platanus occidentalis*), red maple, Florida elm (*Ulmus americana*), bald cypress, blue beech/ironwood (*Carpinus caroliniana*) and swamp ash (*Fraxinus nigra*).

This forest type is heavily influenced by overflow from the river and distinct species assemblages or zones have been documented based on distance from the riverbank and micro-topography of the site. The variability in forest composition is related to local site characteristics such as the size and slope of the watershed, in combination with soil type and slight elevation differences. Wharton et al. (1982) described six different zones, each with their own set of possible dominance types, based on broad geomorphologic floodplain features.

- *Zone I:* permanent water courses, including river channels, oxbow lakes, and permanently inundated backsloughs
- *Zone II-V:* the active floodplain, including swales (II and III), flats and backswamps (IV), levees, and relict levees and terraces (V).
- *Zone VI*: the floodplain-upland transition to terrestrial ecosystem.

These zones correspond to degrees of inundation and saturation that correspond to the NWI water regime categories as follows:

- *Zone II = Intermittently exposed:* surfacewater is present throughout the year, except in years of extreme drought; the probability of annual flooding is nearly 100% and vegetation exists in saturated or flooded soil for 100% of the growing season

- *Zone III = Semi-permanently flooded*: surfacewater or soil saturation persists for a major portion of the growing season in most years. Flooding frequency ranges from 51 to 100 years per 100 years; flooding duration typically exceeds 25 percent of the growing season.

- *Zone IV = Seasonally flooded*: surfacewater or saturated soil is present for extended periods, especially early in the growing season, but is absent by the end of the season in most years. Flood frequency ranges from 51 to 100 years per 100 years; flood duration is typically 12.5-25 of the growing season.

- *Zone V = Temporarily flooded:* surfacewater is present or soil is saturated for brief periods during he growing season, but the water table usually lies well below the soil surface for most of the season. A typical frequency of flooding is 11 to 50 years out of 100; typical duration is 2-12.5 percent of the growing season

- *Zone VI = Intermittently flooded*: soil inundation or saturation rarely occurs, but surfacewater may be present for variable periods without detectable seasonal periodicity; flood frequency ranges from 1 to 10 years per 100 years, and total duration of flood events is typically less than 2 percent of the growing season.

As previously stated, the NWI water regimes reported for the Waccasassa River are semi-permanently flooded, seasonally flooded and temporarily flooded. The area that corresponds to the bottomland hardwood swamp is reported as semi-permanently flooded, meaning the forests probably most closely corresponds with Zone III as described by Wharton et al. (1982).

4.4.2 Mixed Wetland Forest

Includes mixed wetland forest communities where neither hardwoods nor conifers dominate; the mix can include hardwoods, pine or cypress and can represent a mixed hydric site or a transition between hardwoods and conifers on a hydric/mesic site. This community type is not typically tidally influenced because mixed forests occurring near the coast generally fall under the hydric hammock community type.

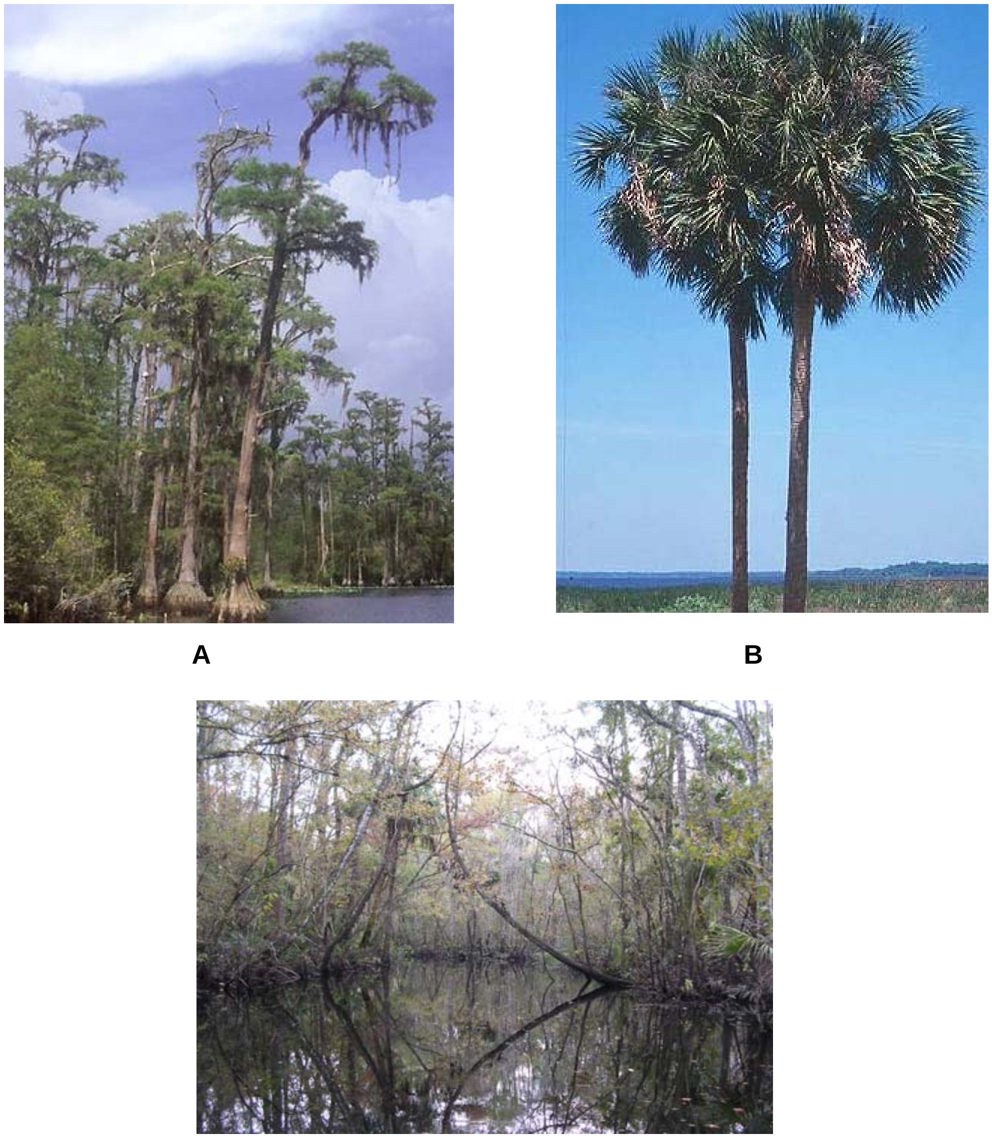


Figure 4-8 Representative photographs of A) bald cypress *(Taxodium distichum),* B) cabbage palm (*Sabal palmetto)*, and C) forested wetland swamp.

4.4.3 Cypress-Pine-Cabbage Palm Associations

This community includes cypress, pine, red cedar and/or cabbage palm in combination so that none of the species can be described as dominant (Figure 4-8). In general, this is a mixed wetland forest with a strong presence of cabbage palm. This category is transitioned between moist upland habitat and hydric habitats (i.e., hydric hammocks) (Florida Fish and Wildlife Conservation Commission, Florida Geographic Data Library Doc., 2004) and typically occurs just landward of the coastal marsh (SRWMD, 1995). In the Waccasassa area, the likely species are bald cypress, loblolly pine (*Pinus taeda*) and cabbage palm.

This vegetation association occurs in areas that could be tidally influenced, meaning that salinity may be a factor at high tide. Bald cypress and cabbage palm were determined to be dominant species in this association type and they also had salinity information reported in the literature. As shown in Figure 4-9, bald cypress has an estimated tolerance range of between 0 and 11 parts per thousand (ppt). Cabbage palm is reported to have a higher salinity range than bald cypress, ranging from 0-27. Cabbage palm is found closer to the coast, often scattered within the coastal marsh. It is likely that at higher salinities, trees exhibit signs of stress (i.e. leaf shed, reduced growth and photosynthesis, etc.). Salinity ranges are highly variable and also depend on the degree of inundation the trees are experiencing. As shown in Figure 4-9, the normal salinity tolerance for bald cypress is likely to be < 5 ppt, while for cabbage palm is < 20 ppt.

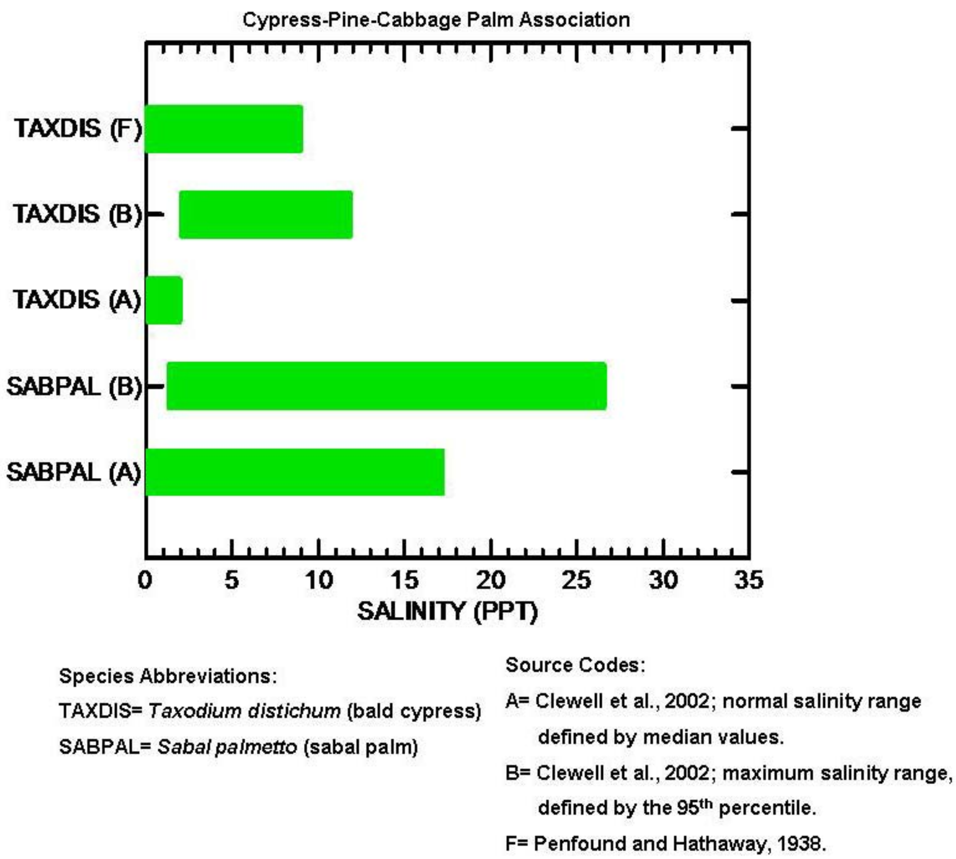


Figure 4-9 Salinity information for representative dominant species in the cypress-pine-cabbage palm vegetative association. Species codes and source codes as indicated.

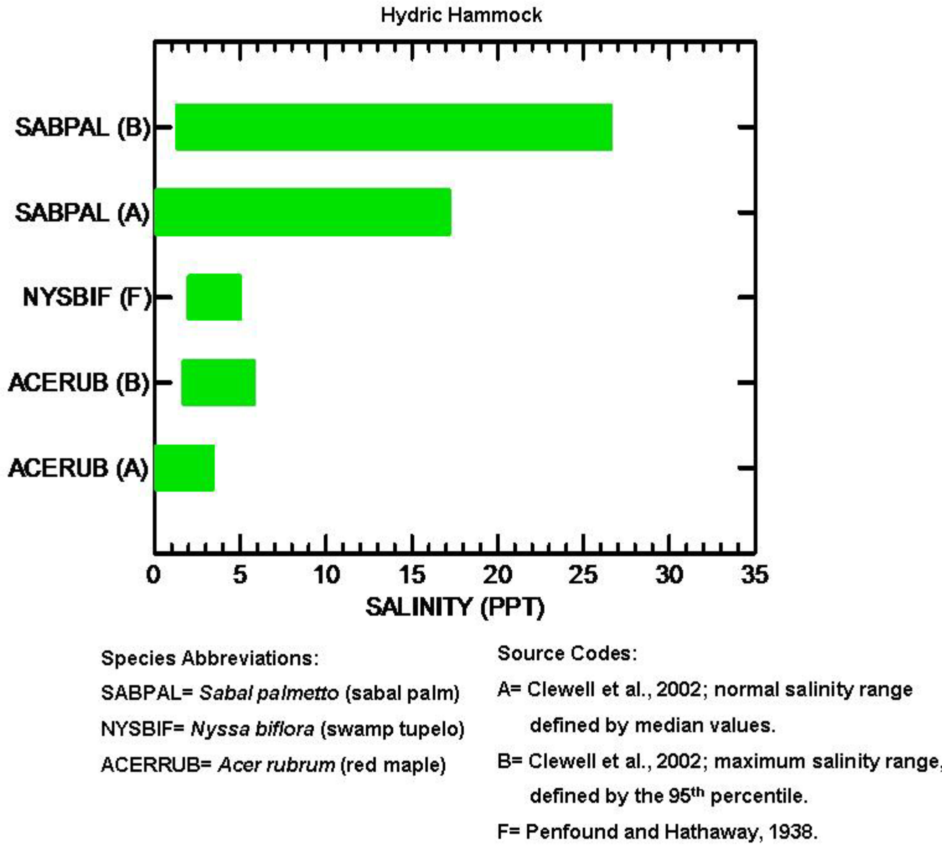


Figure 4-10 Salinity information for representative dominant species in a hydric hammock community. Species codes and source codes as indicated.

4.4.4 Hydric Hammocks

Hydric hammocks are hardwood forests growing on low, flat, poorly drained soils or in areas with a high water table. Hydric hammocks are still-water wetlands, which endure flooding on a less frequent basis and for shorter durations than mixed hardwood communities or cypress swamps. In the Gulf Coast area, limestone outcroppings at or near the soil surface are common. Trees can grow hydroponically on this rock surface. Species assemblages are often dominated by cabbage palm, red maple, and oaks (SRWMD, 1995) and a number of other species have also been described in nearby hammocks: sweetgum (*Liquidamber styraciflua*), loblolly pine, tupelos (*Nyssa spp*.) (Light et al., 2002).

Hydric hammocks occur in areas that can be tidally influenced, meaning that at high tide salinity may be a factor. Cabbage palm, swamp tupelo and red maple were determined to be representative species in this community, which also had salinity ranges available from the literature. As shown in Figure 4-10, cabbage palm has an estimated tolerance range of between 0 and 27 ppt, swamp tupelo up to 5 ppt, and red maple between 0 and 6 ppt. It is likely that trees exhibit signs of stress (i.e. leaf shed, reduced growth and photosynthesis, etc.) at higher salinities. Salinity ranges are highly variable and also depend on the degree of inundation the trees experience. As shown in Figure 4-10, the conservative salinity range for the species other than cabbage palm is likely to be less than or equal to 5 ppt. Cabbage palm is an exception because it is known to occur in higher salinity areas, such as occurring sporadically within a saltmarsh.

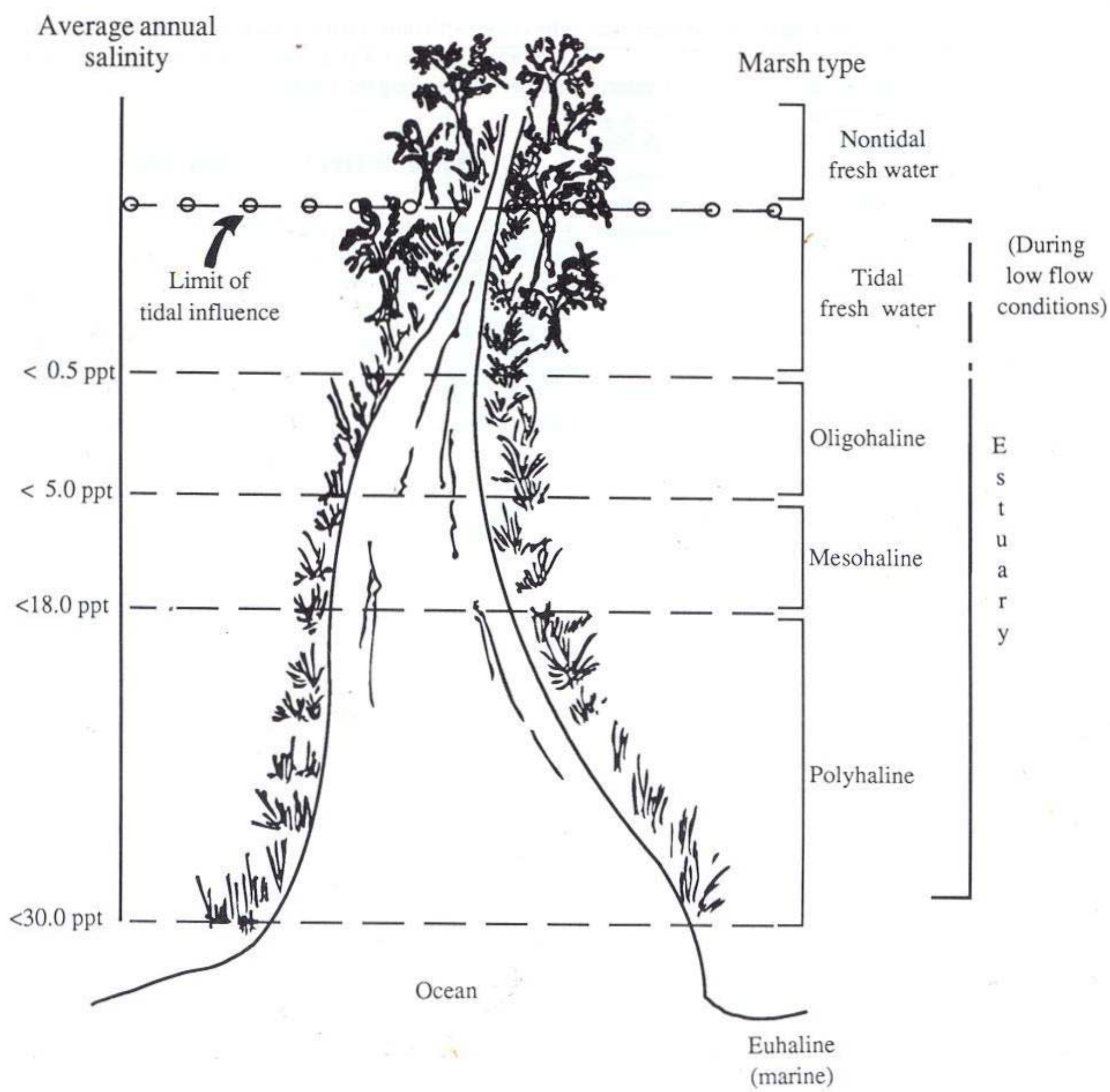


Figure 4-11 Marsh types present in a tidal river system, classified by surface salinity (from Odum and others, 1984).

4.4.5 Tidal Marshes

Tidal marshes provide important habitat for numerous species of fishes and crustaceans. Extensive studies have been conducted in saltmarshes, while tidal fresh-water and oligohaline marshes are less studied (Figure 4-11). However, existing studies have concluded tidal fresh-water and oligohaline marshes also provide valuable habitat for fishes and crustaceans (McIvor et al., 1989; Odum et al., 1988). The marsh may serve several functions for these species, such as providing extended foraging ground, temporary refuge from predation, or essential nursery habitat. The habitat value of tidal marshes (particularly salt or brackish marshes) and estuaries for nektonic organisms has been documented for various geographic areas, including Texas, Louisiana, Georgia, the Carolinas, New Jersey and Delaware (Able et al., 2001; Yozzo and Smith, 1998; Rozas and Reed, 1993; Rozas and Hackney, 1984).

In the Waccasassa River, saltmarshes constitute the dominant community in the intertidal wetland area near the mouth of the river. Because quantitative vegetation studies have not been conducted on the Waccasassa River, qualitative studies on the Waccasassa, and information from marsh habitat on the Lower Suwannee River were used in conjunction with other literature to determine which species likely dominate the different tidal marsh habitats. Dominant plants likely include black needlerush, cordgrasses, sea lavender (*Limonium latifolium*) and seashore saltgrass (*Distichlis spicata*) (Clewell et al., 1999) (Figure 4-12). These higher salinity, tidal marsh communities have been well-studied in estuaries throughout the southeastern U.S. and Florida (Montague and Wiegert, 1990; Coultas and Hsieh, 1997). Concurrently, their ecological value as fishery and wildlife habitat has been well documented (Weinstein, 1979; Boesch and Turner, 1984; Durako et al., 1985). Beck et al. (2000) designated these higher-salinity intertidal marshes (which they termed “mesohaline saltmarsh” and “polyhaline saltmarsh”) as Priority Habitat Targets for conservation in the northern Gulf of Mexico.

A B

C

Figure 4-12 Representative photographs of saltmarsh vegetation A) bulrush *(Scirpus spp.)*, B) sawgrass *(Cladium jamaicence)*, and C) black needlerush *(Juncus romerianus)* marsh.

Species inhabiting a saltmarsh are the most tolerant of high salinities. Polyhaline (salinity 18-30 ppt) conditions typically dominate, although mesohaline conditions (5-<18 ppt) could also occur. Three species were considered representative of the saltmarsh and their salinity ranges are indicated in Figure 4-13. The upward extent of the salinity range for saltmarsh cordgrass and black rush varies between 20 and 35 ppt and 15 and 35 ppt for seashore salt grass.

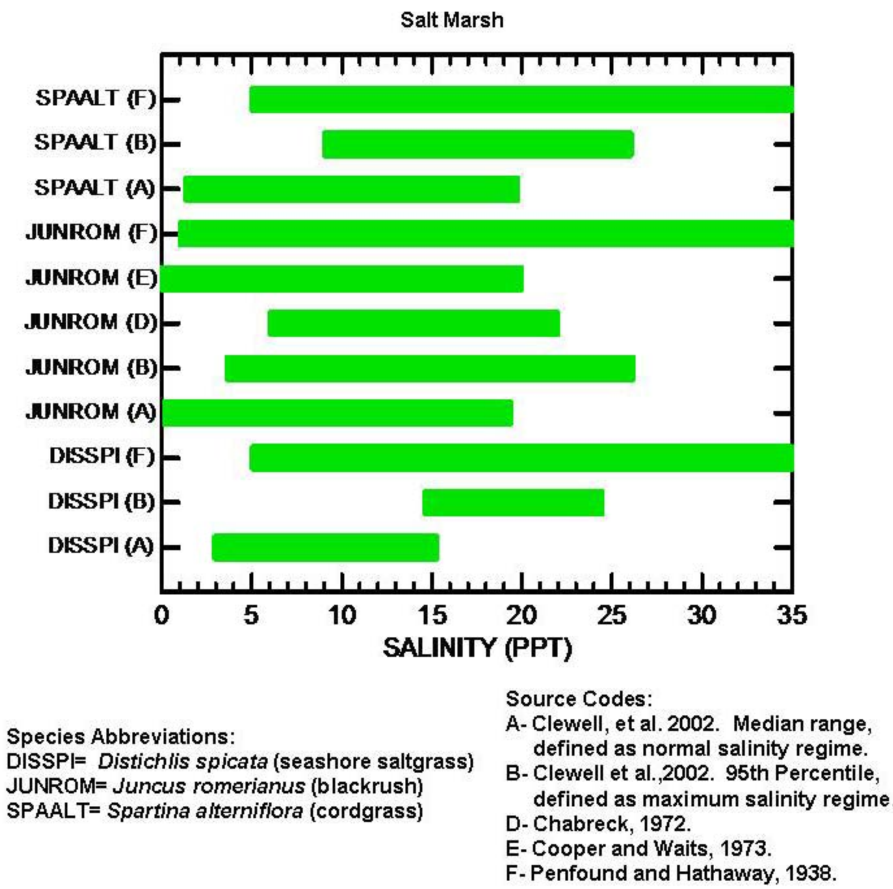


Figure 4-13 Salinity information for representative dominant species in a saltmarsh. Species codes and source codes as indicated.

Oligohaline or brackish tidal marshes occur upstream of the saltmarshes. Dominant plants in these marshes include sawgrass, black needlerush, bulrushes (*Scirpus sp.),* cordgrasses, and lance-leaved arrowhead (*Sagitarria spp*.) (Clewell et al., 1999) (Figure 4-12). As with the tidal, fresh-water marsh communities, few studies have been made on these low-salinity wetlands in

Florida. These low-salinity marshes, in association with their complex of tidal creeks, are known to provide critical nursery habitat for many fishes of commercial or recreational importance (Rozas and Hackney, 1983; Comp and Seaman, 1985), particularly during the earliest larval stages. “Oligohaline saltmarsh” was identified as a priority Habitat Target for conservation in the northern Gulf of Mexico by Beck et al. (2000).

The oligohaline or intermediate marsh is characterized by salinities between 0.5 and 5 ppt. As salinities decrease, diversity increases because more species are able to tolerate the conditions. Several species of bulrush as well as black needlerush and sawgrass are considered representative of this type of marsh and their reported salinity ranges are shown in Figure 4-14. Sawgrass has the most restrictive salinity range with the upward limits being between 7 and 19 ppt.

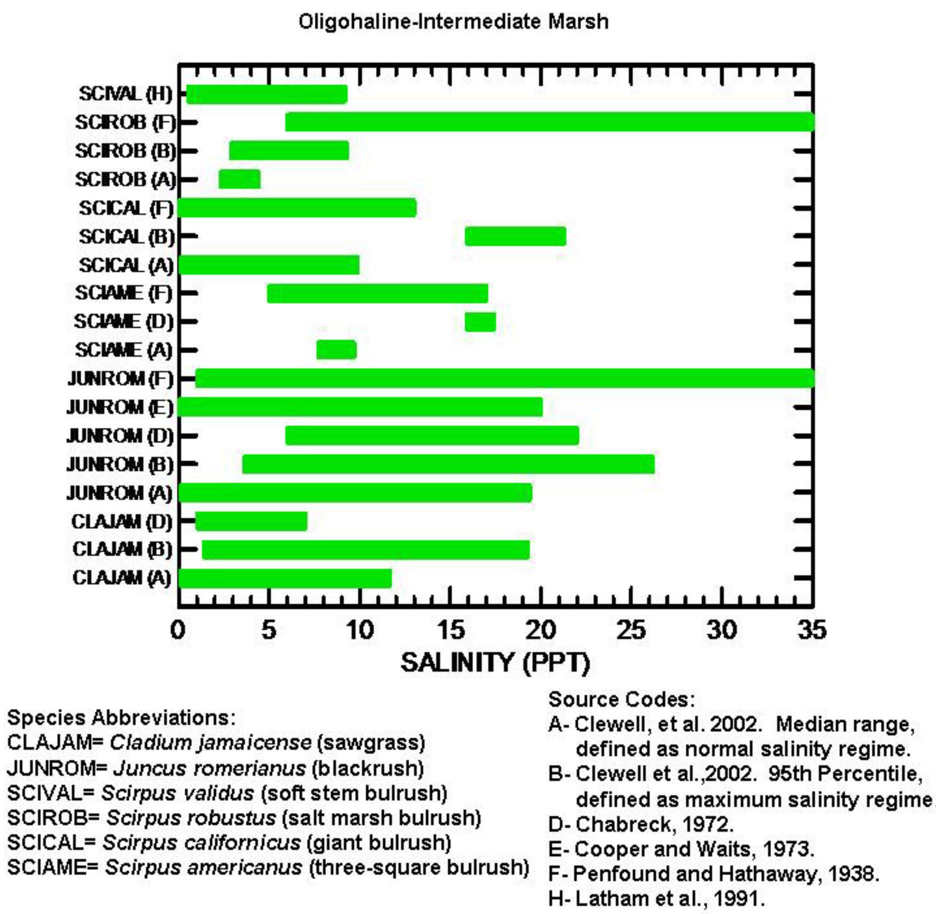
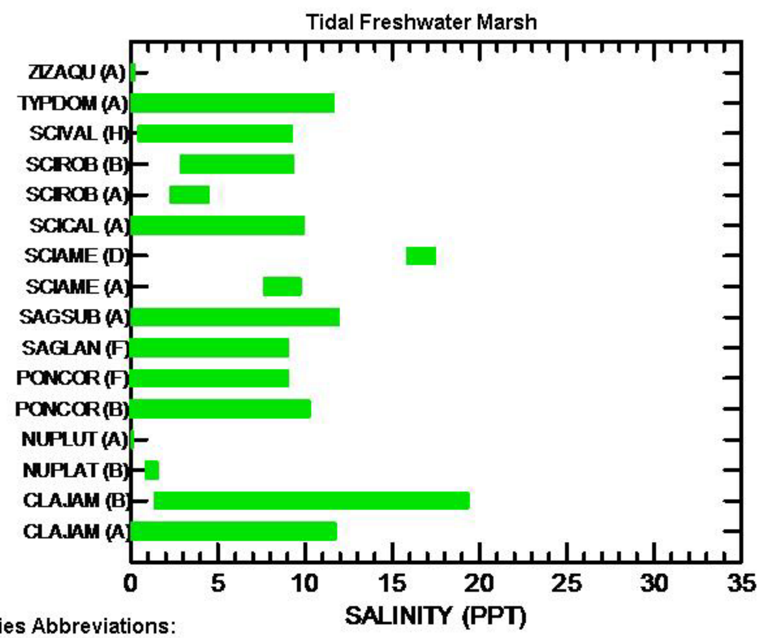


Figure 4-14 Salinity information for representative dominant species in an oligohaline marsh community. Species codes and source codes as indicated.

Another intertidal wetland community is the tidal fresh-water marsh. Dominant plants include sawgrass, bulrushes, wild rice (*Zizania aquatica*), cattail (*Typha domingensis*), arrowhead, water parsnip (*Sium suave*), pickerelweed (*Pontedaria cordata*), spatterdock (*Nuphar luteum*), and other fresh-water emergent marsh plants (Clewell et al., 1999). Overall they have the highest plant diversity of the various tidal marsh community types, as was documented in the Suwannee estuary (Clewell et al., 1999). The general structure and function of tidal fresh-water marsh communities were described by Odum et al. (1984), but few surveys of these coastal wetland types have been made in Florida. The fisheries habitat value of a tidal freshwater marsh is likely equivalent to those of downstream, higher salinity marshes (Odum et al., 1984). Beck et al. (2000) identified “tidal fresh marshes” as a high priority Habitat Target for conservation in the northern Gulf of Mexico.

The tidal fresh-water marsh is characterized by salinities <0.5 ppt. This is the most diverse marsh type. A list of probable species was compiled and the salinity ranges reported in Figure 4-15. Most of these species have salinity tolerances of around 10 ppt, with wildrice and spatterdock being the most indicative of this type of marsh as they tolerate salinities <2 ppt.



Species Abbreviations:
CLAJAM= *Cladium jamaicense* (sawgrass)
PONCOR= *Pontedaria cordata* (pickerel weed)
NUPLAT= *Nuphar luteum* (spatterdock)
SAGSUB= *Sagitarria subulata* (arrowhead)
SAGLAN= *Sagitarria lancifolia* (arrowhead)
SCIVAL= *Scirpus validus* (soft stem bulrush)
SCIROB= *Scirpus robustus* (salt marsh bulrush)
SCICAL= *Scirpus californicus* (giant bulrush)
SCIAME= *Scirpus americanus* (three-square bulrush)
TYPDOM= *Typha domingensis* (cattail)
ZIZAQU= *Zizania aquaitica* (wild rice)

Source Codes:
A- Clewell, et al. 2002. Median range, defined as normal salinity regime.
B- Clewell et al.,2002. 95th Percentile, defined as maximum salinity regime.
D- Chabreck, 1972.
F- Penfound and Hathaway, 1938.
H- Latham et al., 1991.

Figure 4-15 Salinity information for representative dominant species in a fresh-water tidal marsh community. Species codes and source codes as indicated.

Additionally, fresh-water depressional marshes, dominated by sawgrass (*Cladium*) are also likely present near the coast (D. Hoyt, Waccasassa Bay State Preserve, pers. comm.)

4.5 Benthic Macroinvertebrates

4.5.1 Relationship of River Flows to Benthic Macroinvertebrate Community Integrity

Benthic macroinvertebrates are important living resources that can be sensitive to changes in flow regimes, and their relationship to flow is explored in this section. Flow is an influential component of estuarine and riverine systems, and changes to the flow regime can potentially affect many ecological and environmental variables (Figure 4-16). Flow affects the volume and velocity of the river, which directly affects benthos. Under extremely high flows, benthic organisms may be physically washed out of the system. The transport of macroinvertebrates, known as "drift", is important as a mechanism for the establishment of new populations downstream (Benson and Pearson 1987; Matthaei et al. 1997). Aquatic drift can reduce overcrowding and facilitate feeding. Additionally, flow affects the following abiotic parameters, which influence the abundance and distribution of benthos: salinity, dissolved oxygen, sediments, and nutrients.

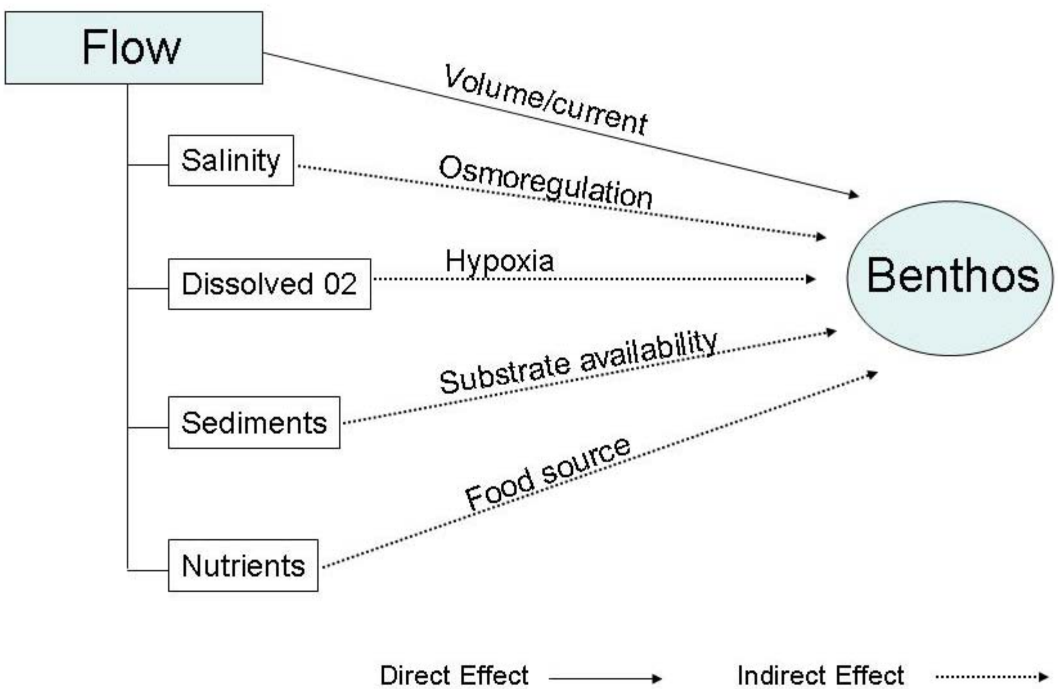


Figure 4-16 Conceptual diagram showing the direct (solid line) and indirect (dashed line) effects of flow on benthos.

Salinity is considered to be the primary physical factor that affects the biota of tidal rivers. In a tidal system, the salinity gradient will shift upstream or downstream due to natural variations in flow. Salinity is largely influenced by the amount of fresh-water inflow entering the system, and it is typically negatively correlated with flow in tidal rivers. A secondary contributor to fresh water in an estuarine system is precipitation. During high flow periods, salinity at a particular location is expected to be lower than during an average or low flow year. During low flow periods, saline water may extend further upstream, facilitating habitat expansion for estuarine species while displacing fresh-water organisms.

Many benthic species are limited in range by the physiological challenges and stresses associated with variable salinity environments. Osmotic limitations restrict the ability of many fresh-water species from using habitats in downstream portions that are tidally influenced. Marine species also face osmotic problems, which restrict access to upstream, fresh-water habitats. Estuarine species typically tolerate a wide range of salinities, although they may have discrete "preferences" for optimal reproduction and growth. Salinity is less of an acute stressor and more a chronic stressor for estuarine invertebrates. For example, a common estuarine isopod, *Cyathura polita*, can complete its life cycle over salinities ranging from 0 to 30 ppt, although northern populations are capable of osmoregulation in distilled water for up to 12 hours (Kelly and Burbanck, 1976).

Changes in the timing and amount of fresh-water inflow may alter the salinity regime such that shifts in dominant species occur as the physical environment becomes less favorable for some species and more favorable for others. That is, the "preferred" salinity regime may now occur at a different time, in a different location, or occupy a smaller/larger area of the system. For example, the displacement could move a preferred salinity regime to a reach of the river where the sedimentary factors are unfavorable (*cf.* "stationary" *vs.* "dynamic" habitats of Browder and Moore, 1981). Since sediment type is also a key abiotic factor affecting the structure of benthic communities, community structure and function could be altered.

Flow affects dissolved oxygen concentrations by modifying residence times and by physically altering stratification conditions. Increased residence times and stratification may be associated with decreased dissolved oxygen. Alterations in dissolved oxygen conditions may affect the fauna as well.

Current velocity, available source material, and organic input determine substrate composition. The important components of substrate composition are the size of the sediment grains, interstitial space between the grains, and the presence or absence of organic detritus. Coarser grained sediments drop out from the current first, and are typically deposited furthest upstream. Finer grained sediments are carried further downstream, with the finest sediments being carried the furthest. Organic inputs may be of various sizes, ranging from fallen trees to small organic fragments, which also contribute to the substratum. Interstices, or the small pore spaces between sediment particles, form micro-habitats that are used by certain benthic organisms and also form areas where fine-grained organic matter may collect. Generally, biotic abundance and diversity increase with increasing substrate stability and the presence of organic detritus (Allan, 1995).

The magnitude and timing of fresh-water inflows affect the amount of nutrients and organic matter that enters a waterway, such that increased productivity may occur some time after a period of increased flows (Kalke and Montagna, 1989; Bate et al., 2002). Sediment loads to a water body are also increased during high flows. Loadings of contaminants, including metals and organic compounds that bind to smaller particles (Seidemann, 1991) are often associated with increased sediment loads. Additionally, increased sedimentation may suffocate sediment dwelling organisms.

Residence time affects the ability of phytoplankton to take up nutrients, as well as the ability for secondary producers to consume phytoplankton. This extends to other consumers as well. Higher flows are associated with increased nutrient loading. Low flow also allows a longer residence time for chlorophyll and nutrients. During high flow conditions, flushing is more rapid and residence time in the river is reduced (Peterson and Festa, 1984; Jassby et al., 1995; Flannery et al., 2002).

4.5.2 Sources of Benthic Macroinvertebrate Data

4.5.2.1 Freshwater Macroinvertebrates

Data on the composition of freshwater macroinvertebrates in the Waccasassa River were previously summarized (Water Resource Associates, 2005) and reviewed and analyzed (Janicki Environmental, Inc., 2004). The SRWMD, as part of their water-quality monitoring program, have collected benthic invertebrate data at one long-term station (WAC010C1) (Figure 4-1). The macroinvertebrate data are qualitative, as they were collected with a D-frame dip net and targeted selected micro-habitats (e.g., leaf packs, root mats, submerged and emergent aquatic vegetation, woody snag habitat, etc.). While this approach focuses on identifying the full diversity of the system, lack of quantitative data limits certain analyses. Mean species richness for the period of record (1989-2003) was 15, with the 5^{th} percentile value of 10 and 95^{th} percentile value of 20 (Janicki Environmental, Inc., 2004). The total number of species recorded at this station across the period of record was 124. These species were examined based on major taxonomic group with the following results: Chironomidae (30 species), Crustacea (16), Oligochaeta (8), Coleoptera (6), Odonata (6), and Ephemeroptera (4). The remaining species belonged to other groups, which were not looked at individually. Percent abundance was also examined based on major taxonomic group with the following results: Crustacea (26%), Chironomidae (24%), Oligochaeta (13%), Ephemeroptera (2%), and Coleoptera (2%) (Janicki Environmental, Inc., 2004).

4.5.2.2 Estuarine Benthic Macroinvertebrates

Based on our review, there have been only two surveys of the estuarine benthos of the Waccasassa River Estuary and Waccasassa Bay. Culter (1986) reported on the characteristics of the benthos at three stations in the Waccasassa River during October 1985. More recently, the State’s Inshore Marine Monitoring and Assessment Program (IMAP) (Florida Fish and Wildlife Research Institute [FWRI], 2002) surveyed the benthos of Waccasassa Bay at 30 stations during July 2001. To the best of our knowledge, FDEP has not collected benthic macroinvertebrate samples from the Waccasassa River, its tributaries, or Waccasassa Bay.

4.5.3 Analysis of Estuarine Benthic Data

With respect to estuarine benthos, the overall objective was to use the best available data to quantify the effects of salinity on the composition and distribution of the benthos. Community structure analyses of the soft-sediment benthos from the Waccasassa River and Bay were constrained by the extremely sparse database available for this part of Florida. These data did not afford any opportunity to compare the effects of different flow regimes on the composition and structure of the benthos in Waccasassa River and Bay. These data only permitted a cursory evaluation of relationships between the benthos and salinity, sample depth, sediment characteristics, and dissolved oxygen. The following constraints need to be recognized when interpreting the results of these data analyses:

- Two different, albeit quantitative, types of sampling gear were employed;
- Different seasons and different years were sampled;
- Inconsistencies in taxonomic nomenclature were noted and resolved, when possible;
- The numbers of samples collected from Waccasassa Bay was an order of magnitude higher than the number collected in the estuary;
- Only two of the three estuarine samples and one of the bay samples were collected from low salinity (<5 ppt) environments; and
- Samples were collected during a single flow regime in each sub-area (estuary and bay).

To help offset some of the limitations of the available data, we drew upon regional characterizations of estuarine benthos that were developed by Janicki Environmental, Inc. (2005). This report showed that there are characteristic salinity and sediment zones based upon the distribution of the benthos within tidal rivers ranging from the Peace River in the south northwards to the Waccasassa River. These regional characterizations were incorporated into the analyses of the Waccasassa River and Waccasassa Bay benthos.

The benthos within 12 southwest Florida tidal rivers was distributed across four salinity ranges that were generally similar to the traditional Venice classification scheme (Cowardin et al., 1979):

- Limnetic-Oligohaline: <8 ppt
- Mesohaline: 8-15 ppt
- Polyhaline: 16-28 ppt
- Euhaline: >28 ppt

The benthos within these rivers was also distributed across five types of sediments, based upon the percent silt and clay content:

- <9 % silt+clay
- 9-19 % silt+clay
- 19-38 % silt+clay
- 38-69 % silt+clay
- >69 % silt+clay

4.5.3.1 Data Analysis Objectives

Data were analyzed to satisfy the following objectives:

- Identify the "dominant" benthic taxa within both the Waccasassa River and Waccasassa Bay

- Determine the association between a suite of abiotic variables, including salinity, and three biotic variables for Waccasassa Bay.

    - The abiotic variables included:

        - Salinity;

        - percent of silt+clay in the sediments;

        - percent of organic matter in the sediments; and

        - the depth at which the benthic samples were collected.

    - Biotic variables included:

        - total numbers of organisms m^{-2} (as a measure of standing crop);

        - numbers of taxa (or taxa richness); and

        - Shannon-Wiener diversity.

- Determine the spatial structure of benthic assemblages within the Waccasassa River and Waccasassa Bay;

- Determine whether the distribution of salinity and other abiotic variables could explain the observed spatial patterns.

The analyses should provide some insight into the extent to which salinity and other abiotic variables affect the composition and structure of the benthos within the Waccasassa River and Waccasassa Bay.

4.5.4 Results

4.5.4.1 Taxonomic Composition and Dominance

Approximately 285 distinct taxa have been identified from benthic collections in Waccasassa River and Bay. The July 2001 IMAP sampling produced a species inventory including at least 259 taxa (FFWRI, unpublished data) and at least 67 taxa were identified in Culter's (1986) study. The two studies had at least 22 taxa in common. Twenty-four of the 67 river taxa are generally considered fresh water or tolerant of very low salinities (*e.g.*, chironomid larvae, some oligochaetes; Culter 1986).

“Dominance” was calculated as the geometric mean of a taxon's percent occurrence and percent composition. Thus, it integrates the measures of how widespread an organism is in the study area (percent occurrence) with its contribution to the overall standing crop (percent composition). Dominant taxa” (Table 4-1) in the Waccasassa River during October 1985 included the tanaid *Halmyrapseudes bahamensis*, the tubiculous amphipod *Cerapus benthophilus*, and the polychaete *Amphicteis gunneri*. Waccasassa Bay dominants included the polychaetes *Monticellina dorsobranchialis* and *Mediomastus ambiseta,* and the amphipod *Erichthonius brasiliensis.*

The dominant taxa in both the Waccasassa River during October 1985 and Waccasassa Bay during July 2001 were typical of taxa tolerant of mesohaline and polyhaline salinities (cf. Janicki Environmental, Inc., 2005).

Table 4-1 Ranked dominant benthic macroinvertebrate taxa from the Waccasassa River (3 samples) and Waccasassa Bay (30 samples). Dominance was calculated as follows: (% occurrence x % composition) $^{-1/2}$

Waccasassa River October 1985	Percent Occurrence	Percent Composition	Dominance
Halmyrapseudes bahamensis	100.0	62.0	78.7
Cerapus benthophilus	66.7	7.9	23.0
Amphicteis gunneri	100.0	3.3	18.2
Grandidierella bonnieroides	100.0	2.9	17.1
Mediomastus sp.	33.3	7.6	16.0
Streblospio gynobranchiata	33.3	5.4	13.4
Ampelisca abdita	66.7	1.6	10.4
Mesanthura floridensis	66.7	0.8	7.4
Tubificoides sp. C	66.7	0.7	6.9
Uromunna sp.	66.7	0.6	6.6
Polypedilum sp.	66.7	0.6	6.5
Cyclaspis varians	33.3	1.1	5.9
Edotea triloba	66.7	0.4	5.4
Coelotanypus sp.	66.7	0.4	5.3
Ablabesmyia sp.	66.7	0.3	4.5
Gammarus tigrinus	66.7	0.2	3.8
Polymesoda caroliniana	66.7	0.2	3.8
Stictochironomus	33.3	0.4	3.6
Limnodrilus hoffmeisteri	33.3	0.3	3.1
Nemertea-genera undetermined	33.3	0.3	2.9

Table 4-1 Continued.

Waccasassa Bay July 2001	Percent Occurrence	Percent Composition	Dominance
Monticellina dorsobranchialis	83.3	8.6	26.9
Erichthonius brasiliensis	23.3	9.1	14.6
Mediomastus ambiseta	50.0	4.1	14.3
Halmyrapseudes sp. A	16.7	11.7	14.0
Scoletoma verrilli	56.7	3.0	13.0
Mysella planulata	56.7	2.1	10.9
Nucula aegeenis	53.3	2.0	10.3
Aricidea taylori	70.0	1.4	10.0
Mediomastus sp.	36.7	2.6	9.7
Fabricinuda trilobata	53.3	1.4	8.6
Tharyx sp.	36.7	2.0	8.6
Phascolion sp	53.3	1.3	8.4
Cirrophorus lyra	46.7	1.4	8.1
Leitoscoloplos robustus	66.7	0.9	7.9
Heteromastus filiformis	46.7	1.1	7.2
Xenanthura brevitelson	36.7	1.4	7.1
Exogone rolani	36.7	1.3	6.9
Mitrella lunata	50.0	0.9	6.8
Podarkeopsis levifuscina	66.7	0.7	6.7
Nuculana acuta	33.3	1.3	6.7

4.5.4.2 Association Analyses

Pearson correlation coefficients were calculated for the Waccasassa Bay data to examine the association of three univariate community metrics with salinity and other abiotic variables.

Three univariate metrics of community structure were calculated:

- species (or taxa) richness);
- species (taxa) diversity; and
- total numbers of individuals m^{-2} .

Species (taxa) richness is the number of distinct species (taxa) identifiable in a sample. Species (taxa) richness is the simplest representation of “diversity”. Every effort was made to ensure that comparable levels of identification were employed.

Species diversity (Shannon-Wiener diversity, H') is a metric that incorporates both numbers of taxa and the distribution of those organisms within a sample (evenness). For example, one may consider two samples each with 10 distinct taxa. In the first sample there is a single individual of each of the 10 taxa and the evenness is high. In the second sample, if one taxon is represented by 100 organisms and the remaining nine taxa are represented by single individuals, evenness is lower. The former sample would have the higher diversity value.

Salinities in Waccasassa Bay were generally in the polyhaline (16-28 ppt) range, based upon the classification scheme for Florida Gulf Coast estuaries (Janicki Environmental, Inc. 2005) (Table 4-2). There was a significant ($p<0.05$) positive association between both numbers of taxa and Shannon-Wiener diversity with salinity (Figure 4-16). The relationship between total abundance of benthic invertebrates and salinity was not significant ($p>0.05$).

Mud-sized sediments (>25.95% silt + clay; *cf.* Grabe and Barron 2004) predominated in Waccasassa Bay. The percent silt and clay generally fell in the 19% to 38% silt+clay category identified for Florida Gulf Coast estuaries (Janicki Environmental, Inc. 2005) (Table 4-2). Total organic carbon concentrations ranged from 3,300 to 33,000 ppm dry weight (Table 4-2). The associations between numbers of taxa, Shannon-Wiener diversity, and benthic abundance vs. both % silt + clay and total organic carbon were not significant ($p>0.05$).

Sample depths occurred over a fairly narrow range (0.6 to 7.2 ft. or 0.2 to 2.2 m; Table 4-2). Diversity was positively associated with depth (Figure 4-16); neither numbers of taxa nor abundance were associated with depth ($p>0.05$).

Near-bottom dissolved oxygen concentrations were generally >5 mg/L in Waccasassa Bay (Table 4-2). Numbers of taxa were positively associated with dissolved oxygen (Figure 4-17). Neither Shannon-Wiener diversity nor abundance were correlated with dissolved oxygen ($p>0.05$).

Pearson correlation coefficients between salinity and the other abiotic variables ranged from 0.26 (depth) to 0.51 (pH); p values for these correlations ranged from 0.06 to 1.00.

Salinity was shown to be positively correlated with both the numbers of taxa and diversity but not overall density of benthic organisms. This relationship is consistent with the general relationship between salinity and numbers of species described by Remane in 1934. Sediment characteristics, however, were not associated with any of these metrics. The numbers of taxa were also higher at higher concentrations of dissolved oxygen.

Table 4-2 Summary of the mean and 95% confidence limits for seven abiotic variables in Waccasassa Bay, July 2001.

Parameter	Mean	95% Confidence Limit
Depth (m)	1.0	0.8-1.1
Dissolved Oxygen (mg/L)	5.6	5.1-6.1
pH	7.87	7.77-7.97
Salinity	21.5	19.1-23.9
Sediment Percent Silt+Clay	33.7	29.3-38.1
Temperature (^oC)	28.1	27.6-28.7
Sediment Total Organic Carbon (ppm)	15,917	12,927-18,907

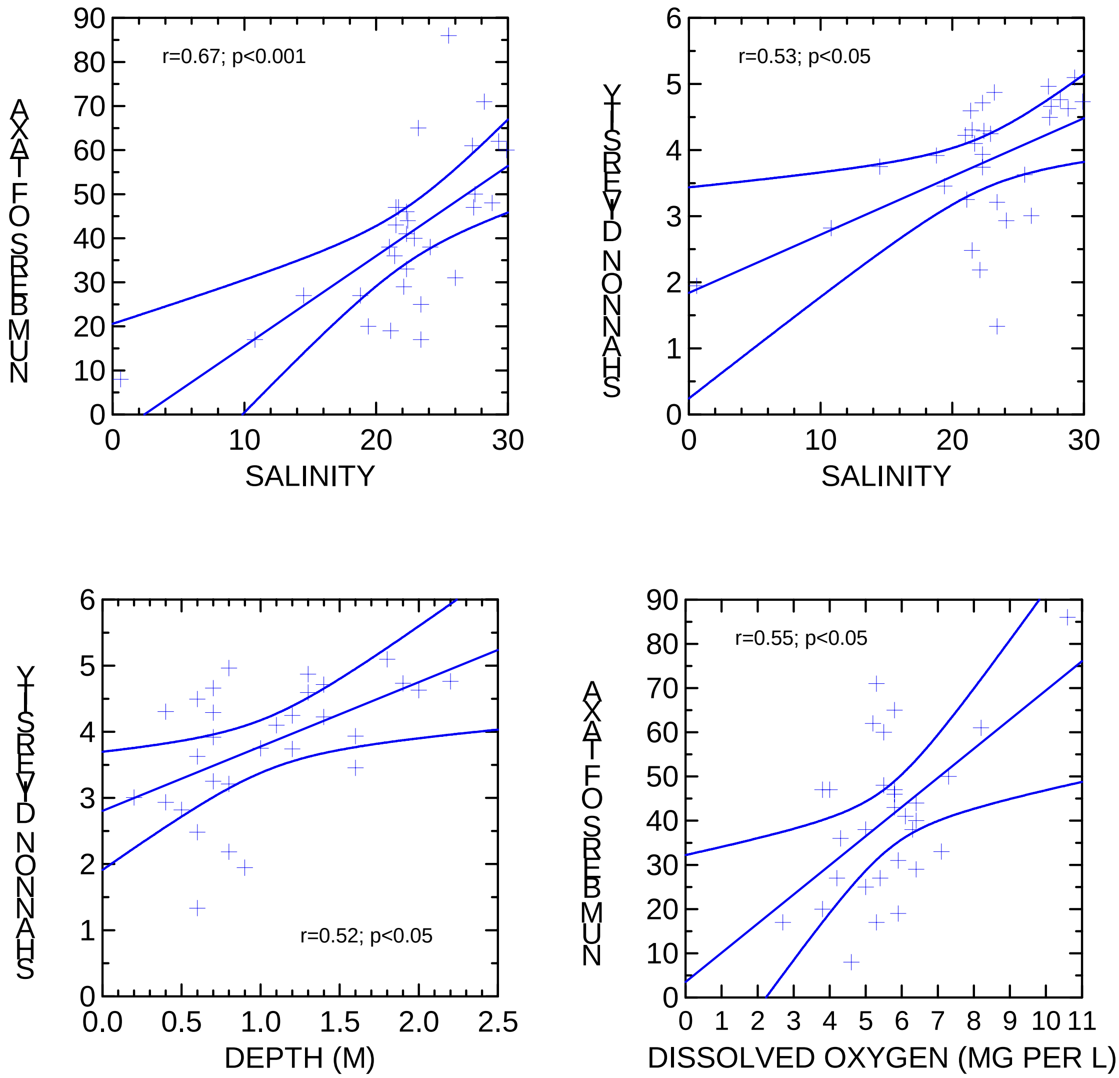


Figure 4-17 Statistically significant ($p<0.05$) associations between univariate community metrics (numbers of taxa and Shannon-Wiener diversity) *vs*. near-bottom salinity, sample depth, and near-bottom dissolved oxygen, Waccasassa Bay (July 2001).

4.5.4.3 Multivariate Analyses

Numerical classification ("cluster" analysis) was used to identify both groups of stations, based upon the similarity of the composition of the benthos, and groups of species with similar spatial distributions. The multivariate structure of the benthic community is then further evaluated by comparing the identified groups of stations not only by their biotic composition but by their relationships to abiotic factors, particularly salinity, that can affect the types of organisms that comprise the benthos.

Community structure was defined as Bray-Curtis similarity (Boesch, 1977) using the percent composition of each sample ("percent similarity"). The choice of "percent similarity" was dictated by the desire to analyze river samples, collected by cores, with bay samples, collected by a much larger "grab" sampler. Group average clustering was used to represent the relationships as a dendrogram (tree diagram).

"Meaningful" groups of stations-dates were defined using a "variable" stopping rule. Boesch (1977) suggests that variable stopping rules may be more appropriate than "fixed" stopping rules for ecological data.

ANOSIM ("analysis of similarity"; Clarke and Warwick, 2001) was applied to determine whether benthic community structure differed between the groups that were identified in the cluster analysis. Salinity zones were not tested because virtually all of the measured salinities were in the polyhaline class. ANOSIM computes a statistic based upon the ranks of dissimilarities between samples.

SIMPER ("similarity percentage") was used to rank the various taxa's contribution to the dissimilarity between the river and bay samples (Clarke and Warwick, 2001). SIMPER objectively identifies those taxa that explain relatively large proportions of the similarity within a category (e.g., salinity class) as well the proportional dissimilarity between the members of these categories.

Nine station groups were subjectively identified in the cluster analysis (Figure 4-18). The Waccasassa River stations proper formed their own Group (Group A). Group B stations were generally located in smaller creeks that flow to the Bay (Figure 4-19). Group C stations were located immediately bayward of the river. The stations in Withlacoochee Bay, to the south, formed Group I. The stations forming Group G were situated in the vicinity of Low's Bay, south of Turtle Creek Point and north of Withlacoochee Bay (Figure 4-19). Group H stations were directly bayward of Group C. Groups D and E were each composed of a single sample and not treated in any detail.

The predominant habitat in Waccasassa Bay was polyhaline (16 to 28 ppt) mud (>25.95% silt+clay) (Table 4-2). Polyhaline sand habitat was the second most frequently occurring. Groups C, F, G, and I represented mainly polyhaline mud habitat. In contrast, the Group B creek stations represented a wide variety of habitats, differing along both salinity and sediment gradients. The stations in Group H sediments were primarily sand.

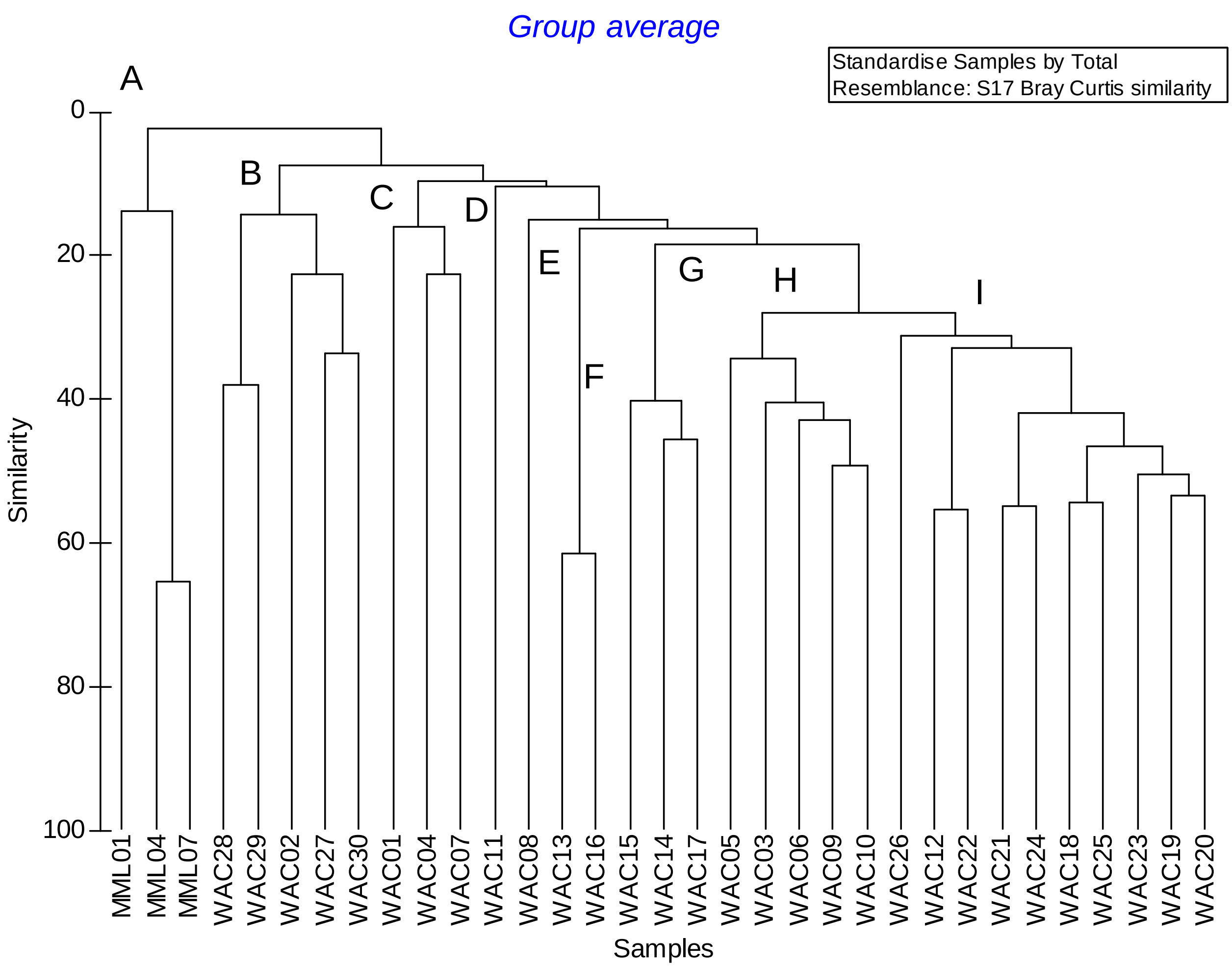


Figure 4-18 Dendrogram depicting the resemblance of benthic stations in the Waccasassa River (October 1985) and Waccasassa Bay (July 2001).

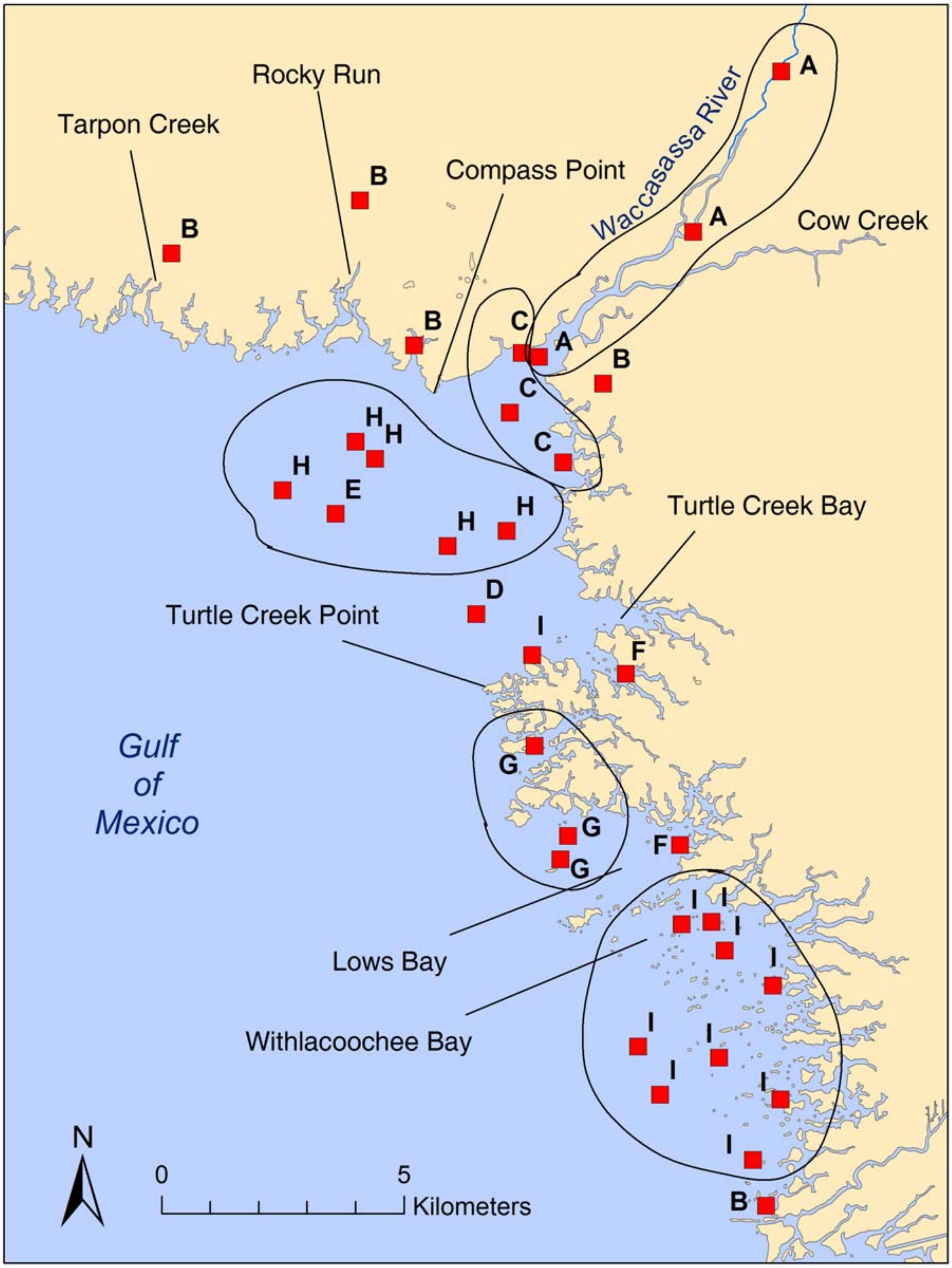


Figure 4-19 Map showing the locations of benthic sampling stations in the Waccasassa River and Waccasassa Bay, coded by station groups (A-I; *cf*. Figure 4-18).

Analysis of variance was used to test for differences in mean values between these groups for both biotic and abiotic factors. Most of the variables were either $\log_{10}$ n+1 or arc-sine transformed to normalize their distributions; Shannon-Wiener diversity and pH were not transformed. Where the overall test statistic was significant (p<0.05), a *post hoc* test (Bonferroni multiple comparison test) was applied to compare paired category means.

Numbers of taxa, and to a lesser extent, diversity, were oriented along an onshore-offshore axis in Waccasassa Bay. The mean number of taxa differed between station groups (p<0.001) and Group B stations (tidal creeks) had the lowest mean number of taxa (Figure 4-20). Mean diversity was also lower (p=0.002) in the creeks (Group B stations) than in Turtle Creek Point and Low's Bay (Group G) (Figure 4-21). Overall benthic standing crop differed between station groups (p<0.001) (Figure 4-22). The mean density at the Group F stations was greater than that of Groups B, C, H, and I; the single Group D station had a higher density than that of Groups B and I.

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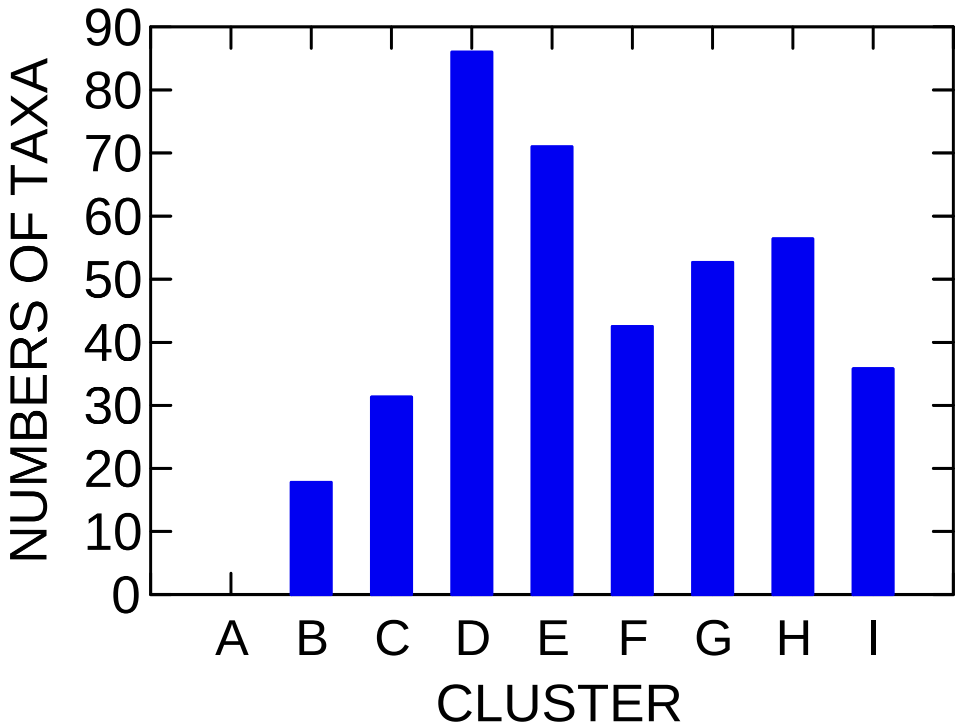


Figure 4-20 Mean numbers of taxa by cluster (station group; *cf.* Figure 4-15). Differences in sampling methods preclude calculating a mean value for group A stations in the Waccasassa River proper.

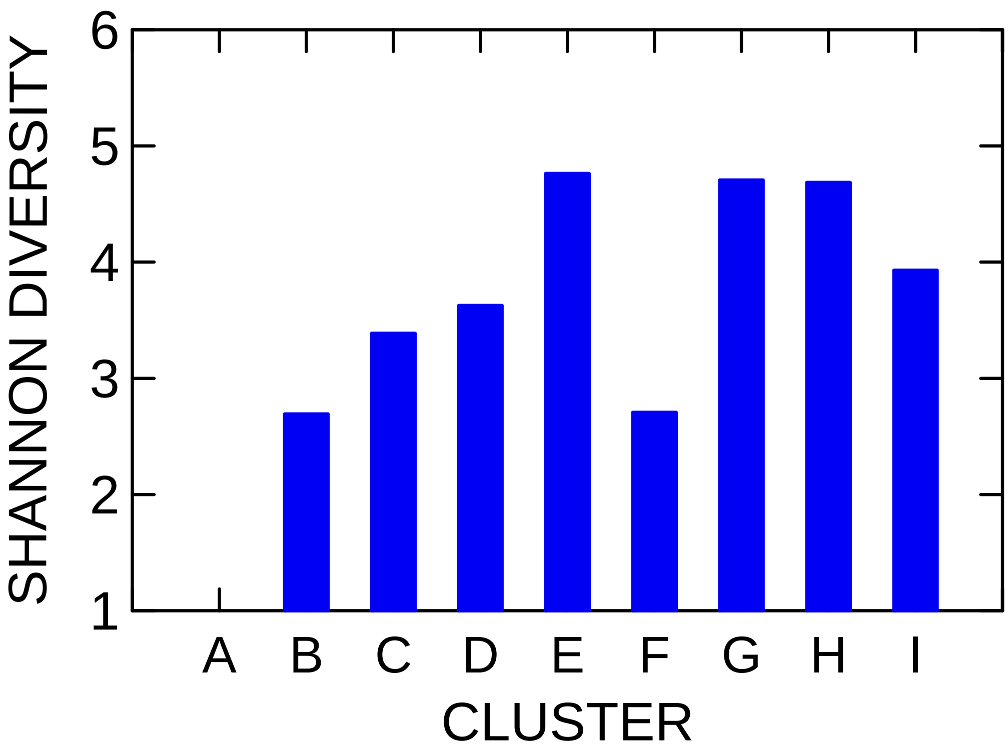


Figure 4-21 Mean Shannon-Wiener diversity by cluster (station group; *cf.* Figure 4-15). Differences in sampling methods preclude calculating a mean value for group A stations in the Waccasassa River proper.

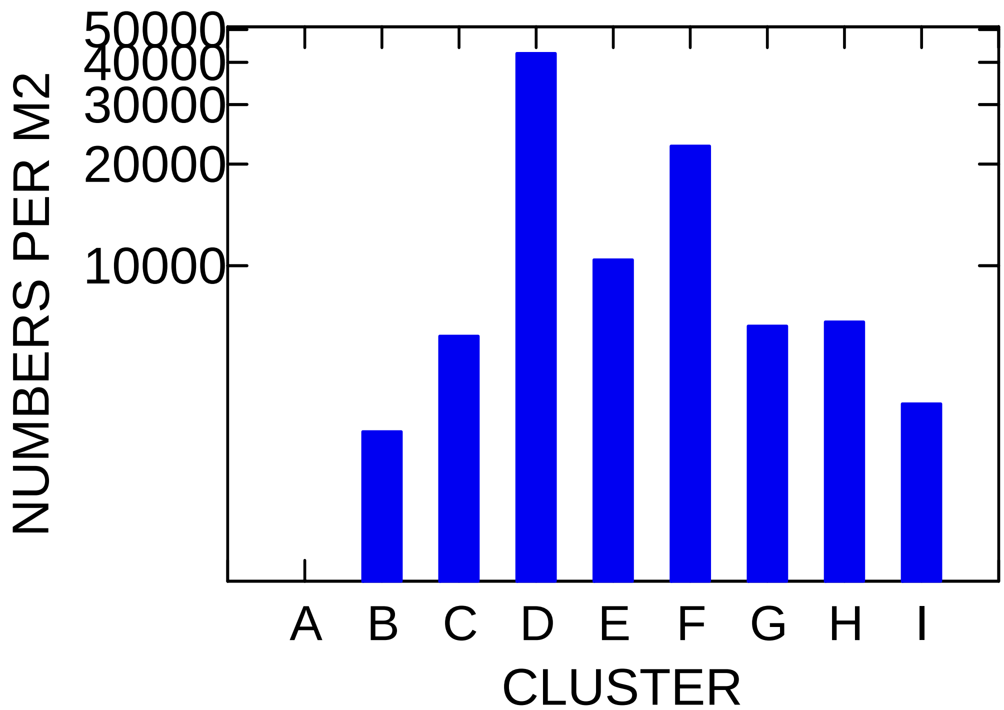


Figure 4-22 Mean density of benthic organisms by cluster (station group; *cf.* Figure 4-15).

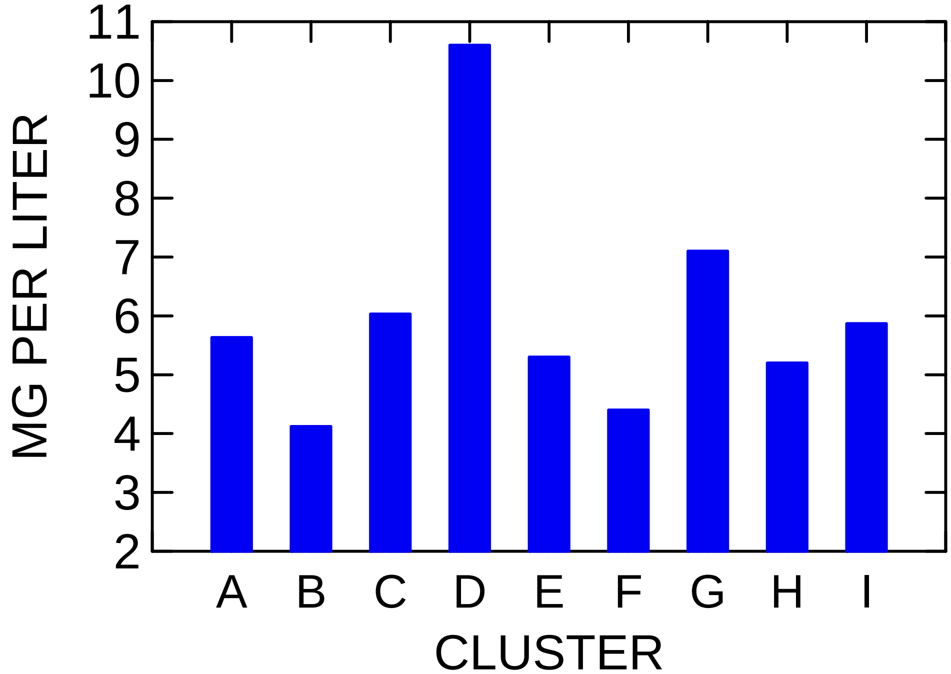


Figure 4-23 Mean concentrations of dissolved oxygen by cluster (station group; cf. Figure 4-15).

ANOSIM (Analysis of similarities) showed that the benthic communities were similar between sediment classes (p=0.4). The benthic assemblages within Groups H and I were most often dissimilar from other assemblages, followed by Group B (Table 4-3). SIMPER analysis showed that the stations in Groups H and I were those at which the polychaete *Monticellina dorsobranchialis* accounted for >14% of the standing crop (Table 4-4). The stations in Group B had a high proportion of *Mediomastus* sp. (Table 4-4). Two species of *Mediomastus* are present in the study area, and *Mediomastus ambiseta* was present in many more samples than *Mediomastus californiensis*, which was not listed as dominant (Table 4-1).

PRIMER's BIO-ENV procedure (Clarke and Warwick 2001) was used as an exploratory tool to ascertain whether benthic community structure within Waccasassa Bay was associated with salinity, temperature, percent silt + clay and percent organic content of the sediments, depth, and dissolved oxygen. The objective was to find a matrix of some combination of (normalized) abiotic variables that provided a "best fit" with the structure of the benthic community in Waccasassa Bay.

The abiotic matrix is formed by calculating Euclidean distances between all station combinations for each subset of abiotic variables tested. The Euclidean distance is the linear distance between any two stations in n-dimensional space. The number of dimensions is the number of abiotic variables (attributes) in the analysis. The statistic used to describe the degree of association is the Spearman rank correlation coefficient (ρ_s; Clarke and Ainsworth 1993). It is not appropriate to assign significance values to ρ_s values (Clarke and Warwick, 2001), and thus this approach can only be used in an exploratory manner. Prior to running the BIO-ENV procedure, PRIMER's RELATE test was used to determine whether there was a statistical relationship between the overall biotic and abiotic matrices. If there was no overall relationship than BIO-ENV would be unnecessary.

Table 4-3. Summary of statistically significant (*p*<0.05) ANOSIM results of pairwise comparisons of benthic community structure between station "Groups". Waccasassa River (October 1985) and Waccasassa Bay (July 2001). Comparisons are ranked by p value. The R statistic is a measure of the difference between that mean rank of similarities between groups – the mean rank similarity within the group and ranges between -1 and 1. If R is close to 0 the groups are not considered to be different (Clarke and Warwick, 2001).

Station Groups	R Statistic	p
B vs. I	0.913	0.002
H vs. I	0.644	0.002
A vs. I	0.997	0.003
I vs. G	0.890	0.003
B vs. H	0.880	0.008
I vs. F	0.876	0.015
H vs. G	1.000	0.018
B vs. G	0.969	0.018
A vs.H	0.969	0.018
C vs. H	0.836	0.018
C vs. B	0.815	0.018
A vs. B	0.785	0.018
C vs. I	0.946	0.030
H vs. F	1.000	0.048
B vs. F	0.709	0.048

Table 4-4 Cumulative percent composition of benthic taxa explaining ≥50% of the similarity within station groups identified in the cluster analysis *(cf.* Figure 4-18), by SIMPER analysis. Waccasassa River (October 1985) and Waccasassa Bay (July 2001). Station Groups D and E are excluded because the within group similarity can not be computed if the sample size is <2.

TAXA	A	B	C	F	G	H	I
Polychaeta							
Aricidea taylori					6.00		3.07
Cirrophorus lyra					4.15		4.04
Exogone rolani					11.63		
Fabricinuda trilobata						4.89	
Galathowenia oculata						2.36	
Heteromastus filiformis		14.72					
Laeonereis culveri		13.12					
Leitoscoloplos robustus			4.02				2.86
Lysilla sp. B			1.60				
Mediomastus sp.		25.97					3.32
Mediomastus ambiseta			17.51			4.99	
Monticellina dorsobranchialis			2.39		6.66	14.65	22.99
Podarkeopsis levifuscina						1.76	
Prionospio heterobranchia					9.17		
Scoletoma verrilli							14.37
Streblospio gynobranchiata		3.20	1.28				
Syllis cornuta						2.16	
Tharyx sp.						6.23	
Mollusca							
Acteocina canaliculata			1.38				
Caecum pulchellum					7.89		
Crepidula fornicata					6.16		
Nuculana acuta						1.96	
Nucula aegeenis						9.74	
Turbonilla conradi			1.60				
Crustacea							
Cerapus sp. B			6.61				
Grandidierella bonnieroides	14.14						
Halmyrapseudes sp. A				54.68			
Halmyrapseudes bahamensis	43.56						

The overall association between biotic and abiotic structure was statistically significant ($p<0.05$)). The subsequent examination of which variables best explained benthic structure showed (Table 4-5):

- The best fit for a single variable was with salinity (ρ_s=0.34) and
- The best fit overall (ρ_s =0.51) was with salinity, dissolved oxygen, pH, and total organic carbon.

However, analysis of variance showed that there were no significant differences between cluster groups for mean salinity (p =0.18), percent silt+clay (p=0.16), and sediment TOC (p =0.11). The station groups did differ by their mean pH (p=0.02) and dissolved oxygen concentrations ($p<0.001$). The Bonferroni test however, was not able to identify differences between station Groups for pH. Dissolved oxygen concentrations were different between the Group G (Turtle Point-Low's Bay) and Group B (creeks) stations (Figure 4-23); the highest dissolved oxygen concentration was measured at the single Group D station.

Table 4-5 Summary of the results of the BIO-ENV test of the association between benthic community structure (percent similarity) and seven abiotic variables (Euclidean distance). Waccasassa Bay, July 2001. ρ_s=Spearman Rank Correlation. X=variable included in the "best fit" computation of ρ_s.

Best Fit: # of Variables	ρ_s	Depth	Dissolved Oxygen	pH	Salinity	% Silt + Clay	Temperature	Total Organic Carbon
1	0.34				X			
2	0.42			X	X			
3	0.50			X	X			X
4	0.51		X	X	X			X
5	0.50	X	X	X	X			X

4.5.5 Discussion

The "best available data" to examine relationships between benthic community structure and salinity in both the Waccasassa River and Waccasassa Bay were limited to two single sampling events 16 years apart. With these constraints, several relationships to salinity were observed.

The benthic assemblage of the Waccasassa River, based upon October 1985 data, was distinct from the July 2001 bay assemblages. Among the 20 ranked dominants in the river and bay, only one taxon was ranked in both areas: the polychaete *Mediomastus* sp(p). Within Waccasassa Bay, assemblages were most readily distinguished by relationships to salinity. Secondary factors included pH, sediment total organic carbon, dissolved oxygen, and depth.

Bay salinities were typically polyhaline (16 to 28 ppt). The species identified from the bay are capable of tolerating a wide range of salinities even if the preferred salinities are relatively high. These include *Monticellina dorsobranchialis* and *Mediomastus ambiseta* (Polychaeta) and the tube-building amphipod *Erichthonius brasiliensis.*

The Waccasassa River dominants include taxa both tolerant and intolerant of the relatively higher salinities near the mouth of the river (e.g., the tanaid *Halmyrapseudes bahamensis*, the tubiculous amphipod *Cerapus benthophilus*). Taxa that may tolerate low salinities but prefer fresh water (*e.g.*, chironomid larvae and the oligochaete *Liminodrilus hoffmeisteri*) were only abundant at the most up-river station (rkm 8.5).

Correlation analysis showed that there was a positive relationship between both numbers of taxa and diversity with salinity, consistent with the generic response to salinity (Remane, 1934). Correlation analysis also showed that there was no relationship between total abundance of benthic invertebrates and salinity.

Correlation analysis also showed that numbers of taxa were typically highest at dissolved oxygen concentrations ranging from 4 to 8 mg/L.

The limited data available for the Waccasassa River and Waccasassa Bay suggest that salinity is the "key" variable associated with the multi-species structure of the benthic community. As noted above, both numbers of benthic taxa and diversity were shown to be higher at higher salinities in the bay. Secondary abiotic variables associated with benthic structure included dissolved oxygen, pH, and sediment total organic carbon.

Within Waccasassa Bay, spatial heterogeneity of the benthos was observed. There was an alignment of station groups along both the north-south axis as well as along an inshore-offshore axis proximate to the river's mouth. The north-south gradient could not be clearly ascribed to any of the`measured abiotic variables. Mean dissolved oxygen concentrations were, however, somewhat lower within group G, offshore of the river's mouth, than within groups H (north) and I (south). Mean numbers of taxa generally declined from north to south and mean numbers of organisms were somewhat lower within group I than in groups G and H.

The inshore-offshore gradient was salinity related. Areas with similar numbers of taxa and, to a lesser extent, diversity, were oriented along an onshore-offshore axis in Waccasassa Bay. Lowest numbers of taxa and lowest diversity values were generally found closer to shore, especially in the creeks draining to the bay.

4.6 Waccasassa Bay Nekton Community

Flow is an influential component of estuarine and riverine systems, and changes to the flow regime can potentially affect many ecological and environmental variables. Flow affects the volume and velocity of the river, which directly and indirectly affects fish in many of the same ways as benthos (see Section 4.5.1). Additionally, flow affects the following abiotic parameters, which influence the abundance and distribution of nekton: salinity, dissolved oxygen, and nutrients.

The analysis of the nekton assemblage in Waccasassa Bay in reference to salinity regime is constrained by having only a single sampling event (July 2001). Inter-annual or seasonal differences in freshwater inflow to the bay or different salinity regimes could not be evaluated with this "snapshot". The objective was to try to identify within-bay differences in salinity and other abiotic and biotic variables that might affect the distribution and composition of the nekton for this single sampling event

4.6.1 Source of Nekton Data

The only available nekton data that we are aware of in the vicinity of the Waccasassa River and Waccasassa Bay were collected as part of the Florida Fish and Wildlife Conservation Commission's Inshore Marine Assessment Program (IMAP) (McRae, 2002). Twenty-seven trawl net samples were randomly selected in the vicinity of Waccasassa Bay, including Withlacoochee Bay, during summer of 2001. Hydrographic profiles were taken at each station and recorded temperature, salinity, dissolved oxygen, and pH. Benthic samples and sediment-related variables such as percent silt and clay and percent organic content, were also collected during the same time frame and integrated into the analyses.

4.6.2 Analysis of Data

The overall objective was to use the best available data to quantify the effects of salinity on the composition and distribution of the nekton in Waccasassa Bay. Any conclusions drawn from the analysis of these data must be tempered with the recognition that this is only a "snapshot" of conditions in Waccasassa Bay and vicinity during the summer of 2001 and no comparable data are available from the Waccasassa River. These data did not afford any opportunity to compare the effects of different flow regimes on the composition and structure of the nekton in the area of interest. These data only permitted a cursory evaluation of relationships between the nekton and salinity, sample depth, sediment characteristics, dissolved oxygen, *etc*. and putative prey items (benthos; See section 4.5).

To assist in the interpretation of these data, habitat types were defined based upon salinity classes and sediment types that had been identified for other studies along the Gulf coast of Florida. Regionally derived salinity categories were developed using principal components analysis (PCA) in previous work conducted on the Lower Suwannee River and Suwannee Sound (Janicki Environmental, Inc. 2005). The following salinity categories were used for post-stratification of nekton (*i.e.,* fish and shrimp) data in the following sections (Figure 4-24):

- <1 ppt
- 1-6 ppt
- 6-20 ppt
- 20-23 ppt
- 23-26 ppt

The majority of the Waccasassa Bay area samples were in the 20 to 23 ppt (n=11) and >23 ppt (n=10) salinity classes. Only five samples were within the 6 to 20 ppt class and a single sample was in the <1 ppt class.

Categories of gross sediment type (*i.e*., sand or mud) are based upon results from Tampa Bay (Grabe and Barron, 2004) and correspond to the criterion currently being used by Peter Rubec of the Florida Fish and Wildlife Research Institute for classifying fish habitats in at least two large Gulf Coast estuarine systems (personal communication 25 February 2005, 7 November 2005).

Sand-sized sediments were defined as those containing <25.95% silt+clay and muds contained >25.95% silt+clay. Twenty-one of the 27 samples were taken from mud habitats.

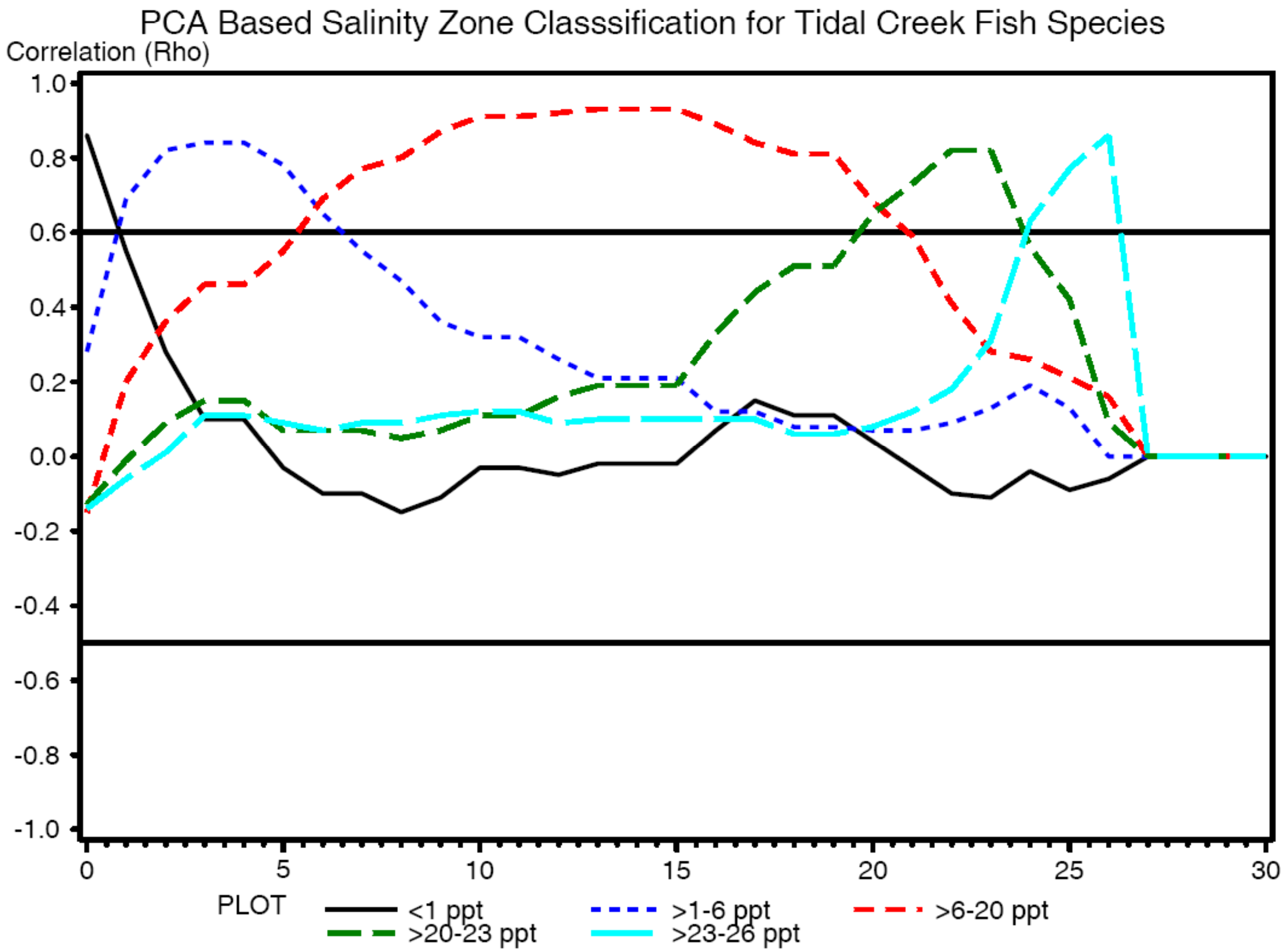


Figure 4-24. Plot of the salinity class principal components analysis based upon nekton taxa collected from tidal creeks in the Lower Suwannee River and Suwannee Sound (Janicki Environmental, Inc. 2005).

4.6.2.1 Data Analysis Objectives

Data were analyzed to satisfy the following objectives:

- Identify the "dominant" nekton species taxa within Waccasassa Bay and vicinity
- Determine the association between a suite of abiotic variables, including salinity, metrics that summarize characteristics of the benthos, which are prey for many finfish and nektonic invertebrates, and metrics characterizing the nekton.
    - o The independent variables included:
        - Salinity;
        - percent of silt+clay in the sediments;
        - percent of organic matter in the sediments; and
        - the depth at which the samples were collected.
        - Numbers of benthic taxa (cf. section 4.5)
        - Benthic standing crop (as numbers m^{-2}; cf. section 4.5)
    - o The dependent biotic variables included:
        - Catch per unit effort (CPUE) (as a measure of standing crop);
        - Total CPUE-bay anchovy (*Anchoa mitchilli*) CPUE (this approach was adopted to offset the effects of high numbers of bay anchovies in the samples which dwarfed the CPUE data of other species)
        - numbers of taxa (or taxa richness); and
        - Shannon-Wiener diversity.

Determine the spatial structure of nekton assemblages within Waccasassa Bay and adjoining waterbodies;

Determine whether the distribution of salinity and other biotic and abiotic variables could explain the observed spatial patterns.

These analyses should provide some insight into the extent to which abiotic (*e.g.*, salinity and sediment characteristics), and prey (*i.e.*, benthic characteristics) affected the composition and structure of the nekton within the Waccasassa Bay vicinity in July 2001.

4.6.3 Results

4.6.3.1 Taxonomic Composition and Dominance

At least 56 fish species and three species of invertebrates were identified from 27 stations in the Waccasassa Bay area during July 2001 (Table 4-6). Dominance was calculated as the geometric mean of percent composition multiplied by percent occurrence for each taxon. The "dominant" species were *Anchoa mitchilli* (bay anchovy), *Bairdiella chrysoura* (silver perch), *Eucinostomus* sp(p). (mojarras) and *Farfantepenaeus duorarum* (pink shrimp) (Table 4-6). *Farfantepenaeus duorarum*, *Eucinostomus* sp(p)., and *Anchoa mitchilli* were each collected in at least two-thirds of the samples. *Anchoa mitchilli* accounted for more than half of the total catch, although 32.8% were collected at a single station (WAC19) and 73.2% were collected at four stations WAC01, -08, -19, and -21).

4.6.3.2 Association Analyses

Pearson correlation coefficients were calculated for the Waccasassa Bay data to examine the association between univariate measures of community structure with a suite of abiotic and biotic variables. Neither CPUE, CPUE-*Anchoa mitchilli*, number of taxa, nor Shannon-Wiener diversity were significantly correlated with any of the selected abiotic or biotic variables ($p>0.9$), including salinity (Table 4-7).

Table 4-6 Twenty-five top-ranked dominant nekton species in Waccasassa Bay, July 2001.

Rank	Taxon	Dominance	Percent Composition	Percent Occurrence
1	*Anchoa mitchilli*	55.0	45.3	66.7
2	*Bairdiella chrysoura*	19.5	10.3	37.0
3	*Eucinostomus spp.*	18.5	5.1	66.7
4	*Farfantepenaeus durorarum*	16.8	4.0	70.4
5	*Menidia spp.*	13.5	7.0	26.0
6	*Lagodon rhomboides*	10.9	2.1	55.6
7	*Cynoscion arenarius*	10.0	2.2	44.4
8	*Anchoa hepsetus*	8.6	1.8	40.7
9	*Etropus crossotus*	7.7	1.3	44.4
10	*Microgobius thalassinus*	7.6	2.2	26.0
11	*Membras martinica*	7.0	2.6	18.5
12	*Syngnathus scovelli*	6.8	1.0	48.1
13	*Opsanus beta*	6.0	1.1	33.3
14	*Chaetodipterus faber*	5.6	0.8	37.0
15	*Leiostomus xanthurus*	5.0	0.8	29.6
16	*Symphurus plagiusa*	4.8	0.7	33.3
17	*Menticirrhus americanus*	4.6	0.7	29.6
18	*Synodus foetens*	4.1	0.4	37.0
19	*Ogcocephalus radiatus*	3.8	0.5	25.9
20	*Arius felis*	3.7	0.9	14.8
21	*Lucania parva*	3.6	1.2	11.1
22	*Gobiosoma robustum*	3.2	0.4	25.9
23	*Microgobius gulosus*	3.1	0.6	14.8
24	*Harengula jaguana*	3.0	0.8	11.1
24	*Oligoplites saurus*	3.0	0.4	22.2
25	*Orthopristis chrysopterus*	2.9	0.4	22.2

4.6.3.3 Multivariate Analyses

ANOSIM (“analysis of similarity”; Clarke and Warwick, 2001) was applied to determine whether nekton community structure differed between salinity classes and sediment type. SIMPER (“similarity percentage”; Clarke and Warwick, 2001) analysis was used to identify the nekton taxa that best explained the differences between the salinity and/or sediment classes that differed in structure.

The ANOSIM test showed that the nekton assemblages differed between salinity classes (Global R statistic=-0.22; p=0.01). The comparison of the adjoining salinity classes showed that the nekton assemblage in the 20 to 23 ppt class differed from that of both the lower (6 to 20 ppt) (p<0.004) and higher (>23 ppt) classes (p<0.016). SIMPER showed that the three taxa explaining the highest proportion of the dissimilarity between these assemblages were *Anchoa mitchilli, Bairdiella chrysoura*, and *Farfantepenaeus duorarum* (Table 4-8). Each of these three species was more abundant in the 20 to 23 ppt salinity class than in either the lower or higher salinity classes (Table 4-8).

The ANOSIM test showed that the nekton assemblages over both sand- and mud-sized sediments were not significantly different (Global R statistic=-0.05; p =0.72).

Habitats are defined by combinations of salinity classes and sediment type. The majority of the Waccasassa Bay samples were from mud sediments and salinities in the 20 to 23 ppt salinity class (n=10) and >23 ppt salinity class (n=10). The ANOSIM test showed that the nekton assemblages over mud-sized sediments differed between salinity classes (Global R statistic=-0.25; p=0.01). Nekton assemblages over mud-sized sediments in the 20 to 23 ppt class differed from those in both the 6 to 20 ppt and >23 ppt classes. SIMPER analysis showed that the three taxa explaining the highest proportion of the dissimilarity between these assemblages were, again, *Anchoa mitchilli, Bairdiella chrysoura*, and *Farfantepenaeus duorarum* (Table 4-9). Each of these three species was more abundant in the 20 to 23 ppt salinity class than in either the lower or higher salinity classes (Table 4-9).

Numerical classification (“cluster” analysis) was used to evaluate spatial patterns in the nekton. Groups of stations, based upon the similarity of the composition of the nekton, and groups of species with similar spatial distributions were identified in these analyses. The multivariate structure of the nekton community was further evaluated by using analysis of variance (ANOVA) to test whether the identified groups of stations differed not only by their biotic composition but also by their relationships to factors, such as salinity, that can affect the types of organisms that comprise the nekton.

Analysis of variance (ANOVA) was used to test for differences in mean values between these groups for both biotic and abiotic factors. Most of the variables were either $\log_{10}$ n+1 or arc-sine transformed to normalize their distributions. Where the overall test statistic was significant (p<0.05), a *post hoc* test (Bonferroni multiple comparison test) was applied to compare paired category means.

Table 4-7 Summary of Pearson correlation coefficients and the association between catch per unit effort (CPUE), CPUE-*Anchoa mitchilli* CPUE, numbers of taxa, and diversity of nekton and selected hydrographic, sediment, and prey variables. Waccasassa Bay, July 2001 (unpublished data, FFWCC IMAP). All Bonferroni probabilities >0.9; n=27.

	CPUE	CPUE- Anchoa mitchilli	Numbers of Taxa	Shannon-Wiener Diversity
Temperature	-0.05	-0.23	-0.08	-0.13
Salinity	0.11	0.04	0.23	0.14
Dissolved Oxygen	0.29	0.30	0.38	0.13
pH	0.01	-0.03	0.10	0.19
% Silt+Clay	0.24	0.08	-0.16	-0.46
% Organics	0.35	0.01	0.11	0.15
Depth	-0.05	0.16	0.02	-0.14
Secchi Disk Depth	-0.14	-0.14	-0.04	0.29
Prey: Benthic Abundance	-0.05	<0.01	0.08	0.19
Prey: Numbers of Benthic Taxa	0.09	-0.02	0.26	0.22

Table 4-8 Summary of ANOSIM and SIMPER analyses comparing the community structure of Waccasassa Bay nekton by salinity class. (CPUE 4th root (n+0.1) transformed; Bray-Curtis similarity).

A. 20 to 23 ppt Salinity Class vs. 6 to 20 ppt Salinity Class (ANOSIM: R statistic=0.46; *p*=0.004)

Species	Mean CPUE: 20-23 ppt Salinity Class	Mean CPUE: 6-20 ppt Salinity Class	% Contribution to Between Group Dissimilarity
Anchoa mitchilli	2.66	0.82	7.77
Bairdiella chrysoura	1.57	0.40	4.81
Farfantepenaeus aztecus	1.68	0.69	4.01
Cynoscion arenarius	1.12	0.31	3.53
Microgobius thalassinus	0.93	0.11	3.52
Menidia spp.	0.12	1.14	3.28
Eucinostomus spp.	0.86	0.56	3.18
Anchoa hepsetus	0.83	0.48	3.10
Etropus crossotus	1.06	0.66	3.06
Syngnathus scovelli	0.94	0.43	2.98
Lagodon rhomboides	0.81	0.44	2.70
Opsanus beta	0.84	0.11	2.63
Symphurus plagiusa	0.72	0.31	2.53
Callinectes sapidus	0.13	0.71	2.49
Chaetodopterus faber	0.77	0.11	2.36

B. 20 to 23 ppt Salinity Class vs. >23 ppt Salinity Class (ANOSIM: R statistic=0.15; *p*=0.016)

Species	Mean CPUE: 20-23 ppt Salinity Class	Mean CPUE: >23 ppt Salinity Class	% Contribution to Between Group Dissimilarity
Anchoa mitchilli	2.66	1.31	7.07
Bairdiella chrysoura	1.57	0.31	5.09
Farfantepenaeus aztecus	1.68	0.70	4.24
Microgobius thalassinus	0.93	0.22	3.77
Etropus crossotus	1.06	0.23	3.69
Eucinostomus spp.	0.86	1.29	3.62
Cynoscion arenarius	1.12	0.32	3.59
Lagodon rhomboides	0.81	0.89	3.29
Anchoa hepsetus	0.83	0.40	3.27
Opsanus beta	0.84	0.34	2.91
Syngnathus scovelli	0.94	0.43	2.84
Membras martinica	0.41	0.36	2.69
Symphurus plagiusa	0.72	0.22	2.66
Menidia spp.	0.12	0.61	2.64

Table 4-9. ANOSIM and SIMPER analyses, by habitat (salinity class x sediment type) Waccasassa Bay nekton, July 2001. ANOSIM tests the probability that the community structure in paired groups of habitats are similar. SIMPER analyses summarize the mean transformed CPUE and relative contribution to the differences between habitats.

A. ANOSIM SUMMARY (Global R statistic= 0.248; *p*= 0.013)

Habitats	R Statistic	*p*
6-20 ppt Mud vs. 6-20 ppt Sand	-0.333	1.00
20-23 ppt Mud vs. 6-20 ppt Mud	0.525	0.007
20-23 ppt Mud vs. >23 ppt Mud	0.275	0.01
>23 ppt Sand vs.20-23 ppt Sand	-0.556	1.00
20-23ppt Mud vs.20-23 ppt Sand	-0.062	0.636
>23 ppt Mud vs.>23 ppt Sand	-0.19	0.808

B. <u>SIMPER ANALYSES</u>

B.1 20 to 23 ppt Salinity Muds vs. 6 to 20 ppt Salinity Muds

Species	Mean CPUE: 20-23 ppt Salinity Mud	Mean CPUE: 6-20 ppt Salinity Mud	% Contribution to Between Group Dissimilarity
Anchoa mitchilli	2.80	0.19	10.01
Bairdiella chrysoura	1.52	0.66	4.69
Farfantepenaeus aztecus	1.64	0.81	3.89
Microgobius thalassinus	1.02	0.19	3.89
Eucinostomus spp.	0.95	0.50	3.61
Cynoscion arenarius	1.05	0.52	3.26
Anchoa hepsetus	0.91	0.81	3.23
Etropus crossotus	0.97	0.63	3.07
Syngnathus scovelli	0.89	0.71	2.88
Menidia spp	0.13	1.14	2.77
Lagodon rhomboides	0.77	0.34	2.59
Symphurus plagiusa	0.70	0.19	2.59
Callinectes sapidus	0.14	0.75	2.55
Opsanus beta	0.78	0.19	2.47

Table 4-9 continued

B.2. 20 to 23 ppt Salinity Muds vs. >23 ppt Salinity Muds

Species	Mean CPUE: 20-23 ppt Salinity Muds	Mean CPUE: >23 ppt Salinity Muds	% Contribution to Between Group Dissimilarity
Anchoa mitchilli	2.80	1.31	7.68
Bairdiella chrysoura	1.52	0.14	4.93
Farfantepenaeus aztecus	1.64	0.71	4.23
Microgobius thalassinus	1.02	0.32	4.03
Eucinostomus spp.	0.95	1.17	3.57
Menidia spp	0.13	0.87	3.53
Cynoscion arenarius	1.05	0.31	3.46
Lagodon rhomboides	0.77	0.90	3.44
Anchoa hepsetus	0.91	0.38	3.43
Etropus crossotus	0.97	0.33	3.34
Membras martinica	0.45	0.51	3.15
Syngnathus scovelli	0.89	0.29	2.81
Opsanus beta	0.78	0.25	2.73

For the cluster analysis, CPUE for each species was 4^{th} root transformed to reduce the effects of numerical dominants on structure. Species that are abundant and wide-spread contribute little to spatial heterogeneity, whereas species that are less abundant and less widely distributed do. The 4^{th} root transformation downweights the contributions from these ubiquitous species and places more emphasis on the contributions from less-widespread species (Clarke and Warwick, 2001). The similarity measure used in this analysis was Bray-Curtis and the clustering algorithm was group average. Meaningful station and taxa groups ("clusters") were identified subjectively. Data were summarized as a two-way coincidence table of the reordered stations and taxa. SIMPER analysis was used to identify the nekton taxa that best explained the between cluster dissimilarity.

Six station groups were subjectively identified in both the normal (stations) cluster analysis (Figure 4-25) and the inverse (taxa) analysis (Figure 4-26). ANOSIM showed that paired comparisons between stations in Cluster D *vs*. clusters B, E, and F had both high R values and low probability values (Table 4-10).

ANOVA showed that only mean dissolved oxygen concentrations (DO) differed between clusters ($p < 0.05$) and the *a post hoc* test showed that stations in Cluster D had a different mean DO than stations in Cluster E ($p = 0.01$). Most of the Group D stations were located in the creeks entering the bay whereas Group B stations were located in nearshore areas of Withlacoochee Bay (Figure 4-27). Mean salinity was 5 ppt lower at the B stations and benthic standing crop at the B stations averaged almost twice that of the D stations (Table 4-11). SIMPER analysis showed that the taxa explaining much of the differences between the two groups included *Membras martinica*, *Microgobius thalassinus* (greater mean CPUE at B), and *Menidia* spp. (more abundant at D stations) (Tables 4-10 and 4-11).

Group E stations were located north of Turtle Creek Point and in Low's Bay (Figure 4-27). Both water column mean dissolved oxygen concentrations and mean benthic standing crop were higher at the E stations (Table 4-11) than the D stations. Groups D and E differed in that mean CPUE of *Eucinostomus* sp., *Anchoa mitchilli*, and *Bairdiella chrysoura* were higher at the Group E stations and *Menidia* spp. were collected at the Group D stations but not at the Group E stations.

Group F stations were also located in the southwestern portion of Withlacoochee Bay, somewhat offshore of the Group B stations (Figure 4-27). The means of the measured abiotic variables and prey variables were quite similar between station groups D and F (Table 4-11). Both *Menidia* spp. and *Bairdiella chrysoura* were much more abundant at the Group F stations (Tables 4-10 and 4-11).

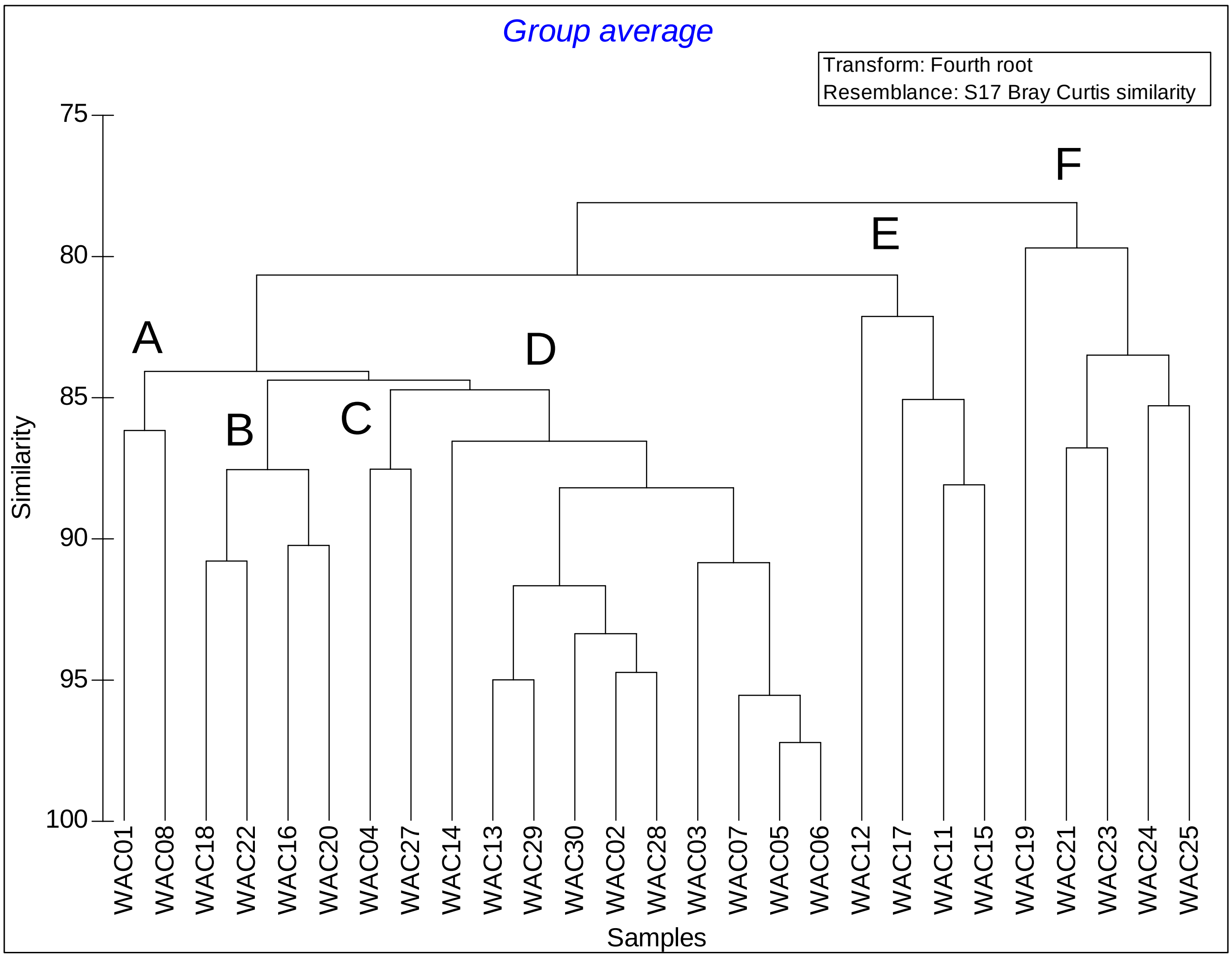


Figure 4-25. Dendrogram depicting the similarity of Waccasassa Bay (July 2001) stations by nekton composition.

Table 4-10 Summary of ANOSIM and SIMPER analyses, Waccasassa Bay nekton, July 2001. ANOSIM tests the probability that the community structure in paired groups of stations. SIMPER analyses summarize the mean CPUE and relative contribution to the differences between station groups in numerical classification analysis.

A. ANOSIM

Groups	R Statistic	*p*
A, B	1	0.067
A, C	1	0.333
C, B	0.929	0.067
D, E	0.926	0.004
D, F	0.925	0.001
E, B	0.885	0.029
A, D	0.796	0.015
A, E	0.786	0.067
D, B	0.775	0.001
B, F	0.763	0.016
D, C	0.737	0.015
E, F	0.606	0.008
C, F	0.582	0.048
C, E	0.536	0.067
A, F	0.436	0.095

B. SIMPER Analyses

Species	Group A	Group B	% Contribution to Between Group Dissimilarity
Anchoa mitchilli	255.00	13.00	72.22
Membras martinica	4.00	23.50	6.68

Species	Group A	Group C	% Contribution to Between Group Dissimilarity
Anchoa mitchilli	255.00	0.50	84.15

Species	Group C	Group B	% Contribution to Between Group Dissimilarity
Membras martinica	0.00	23.50	20.24
Microgobius thalassinus	0.00	18.00	18.48
Anchoa mitchilli	0.50	13.00	12.41
Eucinostomus argenteus	0.00	5.00	5.42
Callinectes sapidus	5.50	0.25	5.18
Eucinostomus spp	0.00	4.25	4.61
Farfantepenaeus durorarum	2.00	5.75	4.25
Microgobius gulosus	4.00	0.00	4.13
Cynoscion arenarius	0.50	3.75	3.04

Species	Group D	Group E	% Contribution to Between Group Dissimilarity
Eucinostomus spp	3.10	37.75	20.91
Anchoa mitchilli	14.40	43.75	20.14
Menidia spp	27.80	0.00	12.29
Bairdiella chrysoura	0.00	21.75	11.64
Lagodon rhomboides	3.50	9.25	5.13
Opsanus beta	0.00	6.00	3.81
Farfantepenaeus durorarum	0.60	6.25	3.56

Species	Group D	Group F	% Contribution to Between Group Dissimilarity
Anchoa mitchilli	14.40	186.60	34.53
Bairdiella chrysoura	0.00	63.80	18.13
Menidia spp	27.80	0.00	9.05
Farfantepenaeus durorarum	0.60	19.80	6.68
Cynoscion arenarius	0.10	14.00	3.60
Etropus crossotus	0.00	5.40	3.02

Species	Group E	Group B	% Contribution to Between Group Dissimilarity
Anchoa mitchilli	43.75	13.00	18.29
Eucinostomus spp	37.75	4.25	18.03
Membras martinica	0.00	23.50	10.56
Bairdiella chrysoura	21.75	0.00	9.92
Microgobius thalassinus	0.00	18.00	8.95
Lagodon rhomboides	9.25	0.00	4.94
Opsanus beta	6.00	0.00	3.20
Farfantepenaeus durorarum	6.25	5.75	2.66

Species	Group A	Group D	% Contribution to Between Group Dissimilarity
Anchoa mitchilli	255.00	14.40	76.74

Species	Group A	Group E	% Contribution to Between Group Dissimilarity
Anchoa mitchilli	255.00	43.75	62.24
Eucinostomus spp	1.50	37.75	10.44
Bairdiella chrysoura	0.50	21.75	5.79

Species	Group D	Group B	% Contribution to Between Group Dissimilarity
Membras martinica	0.30	23.50	17.13
Menidia spp	27.80	0.75	16.30
Microgobius thalassinus	0.00	18.00	15.47
Anchoa mitchilli	14.40	13.00	13.75
Eucinostomus spp	3.10	4.25	4.79
Eucinostomus argenteus	0.50	5.00	4.67
Farfantepenaeus durorarum	0.60	5.75	4.43

Species	Group B	Group F	% Contribution to Between Group Dissimilarity
Anchoa mitchilli	13.00	186.60	34.27
Bairdiella chrysoura	0.00	63.80	17.56
Membras martinica	23.50	0.00	8.22
Microgobius thalassinus	18.00	3.40	6.35
Farfantepenaeus durorarum	5.75	19.80	4.45
Cynoscion arenarius	3.75	14.00	3.22
Arius felis	0.50	7.20	2.26

Species	Group D	Group C	% Contribution to Between Group Dissimilarity
Menidia spp	27.80	0.00	22.49
Anchoa mitchilli	14.40	0.50	14.47
Callinectes sapidus	0.10	5.50	8.28
Microgobius gulosus	0.00	4.00	6.67
Etropus crossotus	0.00	3.50	5.55
Syngnathus scovelli	0.20	3.00	4.42
Lucania parva	4.50	0.00	3.75
Prionotus tribulus	0.00	2.00	3.24
Lagodon rhomboides	3.50	0.00	3.11
Eucinostomus spp	3.10	0.00	2.97
Farfantepenaeus durorarum	0.60	2.00	2.96

Species	Group E	Group F	% Contribution to Between Group Dissimilarity
Anchoa mitchilli	43.75	186.60	38.01
Bairdiella chrysoura	21.75	63.80	14.14
Eucinostomus spp	37.75	0.80	12.79
Farfantepenaeus durorarum	6.25	19.80	4.36
Cynoscion arenarius	0.00	14.00	3.32
Lagodon rhomboides	9.25	2.80	2.71

Species	Group C	Group F	% Contribution to Between Group Dissimilarity
Anchoa mitchilli	0.50	186.60	39.29
Bairdiella chrysoura	2.00	63.80	19.04
Farfantepenaeus duorarum	2.00	19.80	6.81
Cynoscion arenarius	0.50	14.00	3.90
Callinectes sapidus	5.50	0.00	2.57
Chaetodipterus faber	0.00	5.60	2.49
Arius felis	0.00	7.20	2.42

Species	Group C	Group E	% Contribution to Between Group Dissimilarity
Eucinostomus spp	0.00	37.75	25.60
Anchoa mitchilli	0.50	43.75	17.34
Bairdiella chrysoura	2.00	21.75	12.82
Lagodon rhomboides	0.00	9.25	6.99
Opsanus beta	0.00	6.00	4.47
Farfantepenaeus duorarum	2.00	6.25	3.91
Callinectes sapidus	5.50	0.00	3.68
Microgobius gulosus	4.00	3.25	3.38

Species	Group A	Group F	% Contribution to Between Group Dissimilarity
Anchoa mitchilli	255.00	186.60	56.78
Bairdiella chrysoura	0.50	63.80	14.50
Farfantepenaeus duorarum	1.50	19.80	4.53

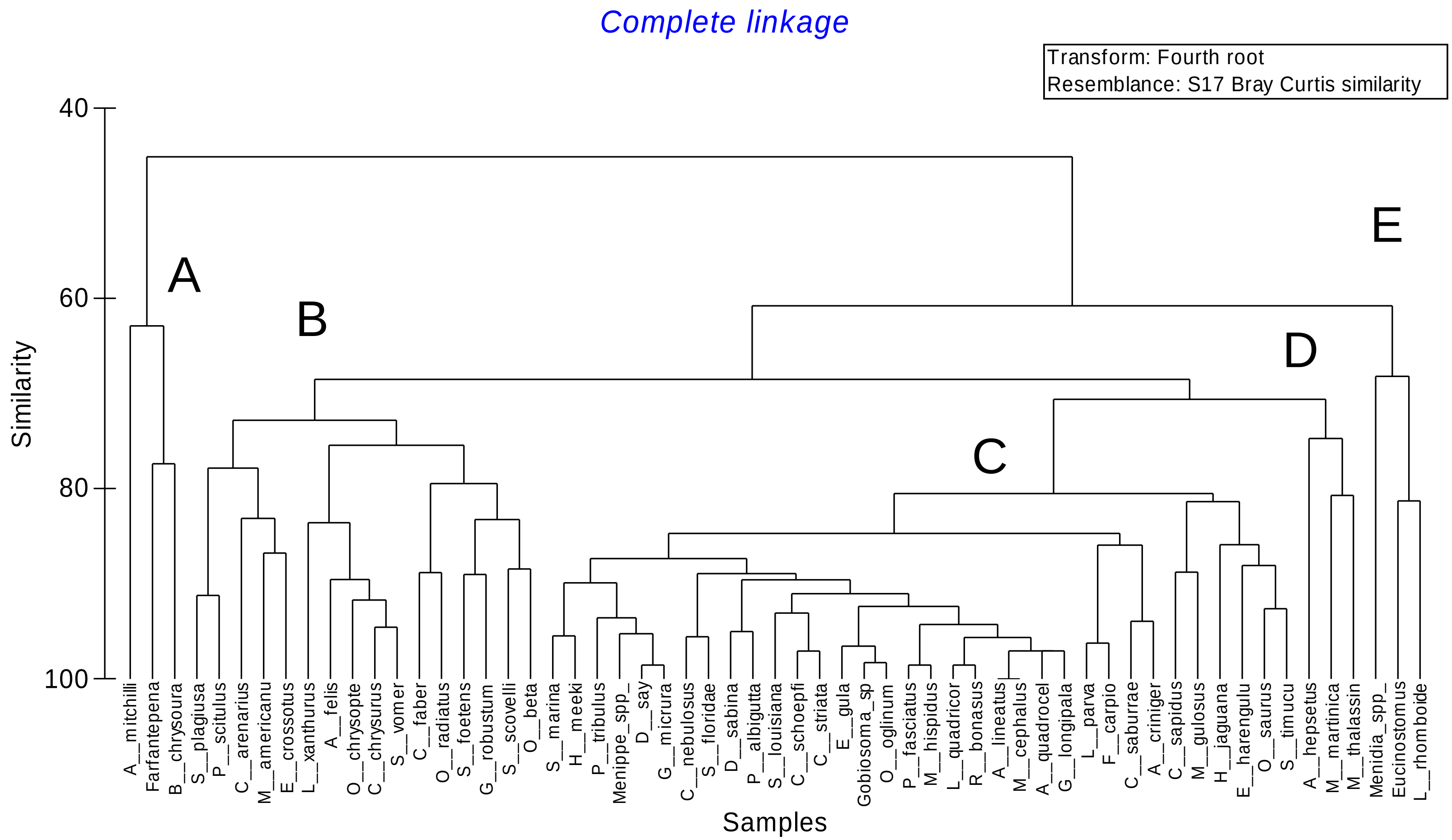


Figure 4-26 Dendrogram depicting the similarity of Waccasassa Bay nekton taxa (July 2001) by station composition. See Table 4-11 for key to the taxa names

Table 4-11 Two-way coincidence table of taxa ordered as in the inverse dendrogram (*cf*. Figure 4-26) and normal (station) cluster (*cf.* Figure 4-25). Cell values are group means*p* values for univariate (Cluster) Analysis of Variance (ANOVA) for each of the abiotic and prey variables (all variables Log_{10} or arc-sine (% silt+clay) transformed) are shown. Nekton taxa means are CPUE.

ABIOTIC AND BIOTIC VARIABLES	*p* (Univariate ANOVA)	A	B	C	D	E	F
Temperature	0.31	29.0	28.8	29.2	27.4	28.3	27.9
Salinity	0.89	25.1	21.8	18.1	20.7	24.4	21.2
Dissolved Oxygen	0.02	6.0	5.2	4.5	5.1	8.3	6.2
pH	0.31	7.85	7.75	7.90	7.82	8.18	7.81
Depth	0.11	1.5	0.6	0.7	1.1	0.6	1.2
Secchi Disk Depth	0.16	0.4	0.6	0.9	0.6	0.8	0.8
% Silt+ Clay	0.83	37.0	33.3	18.0	35.3	34.8	35.4
Organic Content	0.67	19,500	13,100	12,000	15,350	22,250	16,983
Prey: Benthic Abundance	0.50	11,250	10,662	4,250	5,935	15,250	5,029
Prey: Benthic Taxa Richness	0.40	50	34	27	34	57	40
CPUE		291	63.2	29	152	87.5	354.8
Numbers Of Taxa		12	7	12	15	10	22
Shannon-Wiener H’		0.86	1.59	3.11	2.46	2.44	2.63
Taxa Groups	TAXA KEY (Figure 4-x)						
A. *Anchoa mitchilli*	A_MITCHILLI	255	14.4	0.5	43.75	13	186.6
Farfantepenaeus durorarum	FARFANTEPENA	1.5	0.6	2	6.25	5.75	19.8
Bairdiella chrysoura	B_CHRYSOURA	0.5	0	2	21.75	0	63.8

Table 4-11. continued

TAXA		A	B	C	D	E	F
B. *Symphurus plagiusa*	S_PLAGIUSA	1	2.75	1	0	0.75	2.2
Prionotus scitulus	P__SCITULUS	0	0	1	0	1	14
Cynoscion arenarius	C__ARENARIUS	1.5	3.75	0	0.1	0	3.2
Menticirrhus americanus	M__AMERICANU	1.5	1.75	0	0.1	0	4.4
Etropus crossotus	E__CROSSOTUS	1.5	3.75	4	0	0.25	7.2
Leiostomus xanthurus	L__XANTHURUS	0	0	0	1.2	0	2.2
Arius felis	A__FELIS	0	0.5	0	0	0	5.6
Orthopristis chrysopterus	O__CHRYSOPTE	0.5	0	0	0	0.75	2.2
Chloroscombrus chrysurus	C__CHRYSURUS	0	0	0	0.1	0	1.8
Selene vomer	S__VOMER	0.5	0	0	0.1	0.25	1
Chaetodipterus faber	C__FABER	1	0.5	0	0.2	0	3.2
Ogcocephalus radiatus	O__RADIATUS	0.5	0	0	1	0	3.8
Synodus foetens	S__FOETENS	0.5	0	1	0	1.5	
Gobiosoma robustum	G__ROBUSTUM	0	0.5	0	0	2.25	0
Syngnathus scovelli	S__SCOVELLI	0	0.5	0	0.2	3.25	
Opsanus beta	O__BETA	0	0	0	0	6	0
							0
C. *Strongylura marina*	S__MARINA	0	0	1	0.1	0.5	0
Hyporhamphus meeki	H__MEEKI	0	0	1	0	1.75	0
Prionotus tribulus	P__TRIBULUS	0.5	0	3	0	0	0.33
Menippe sp.	MENIPPE_SPP_	1	0	0	0.1	0	0.17
Dasyatis say	D__SAY	0.5	0	0	0	0	0
Gymnura micrura	G__MICRURA	0.5	0	0	0	0	0.17
Cynoscion nebulosus	C__NEBULOSUS	0	0	0	0	1.25	0.33
Syngnathus floridae	S__FLORIDAE	0	0	0	0	1.75	0.17
Dasyatis sabina	D__SABINA	0	0	0	0	0.75	0.33
Paralichthys albigutta	P__ALBIGUTTA	0	0	0	0	0.25	0.5
Syngnathus louisianae	S__LOUISIANA	0	0.25	0	0	0.25	0.33
Chilomycterus schoepfii	C__SCHOEPFI	0	0.75	0	0	0	0.33
Centropristis striata	C__STRIATA	0	0	0	0	0	0.17

Table 4-11. continued

Eucinostomus gula	E__GULA	0	0	0	0	0	1.17
Gobiosoma sp.	GOBIOSOMA_SP	0	0	0	0	0	0.17
Opisthonema oglinum	O__OGLINUM	0	0	0	0	0	1
Paraclinus fasciatus	P__FASCIATUS	0	0	0	0	0.25	0.17
Monacanthus hispidus	M__HISPIDUS	0	0	0	0	0	0.17
Acanthostracion quadricornis	L__QUADRICOR	0	0	0	0.1	0	0.17
Rhinoptera bonasus	R__BONASUS	0	0	0	0.1	0	0
Achirus lineatus	A__LINEATUS	0	0	0	0	0.25	0
Mugil cephalus	M__CEPHALUS	0	0	0	0	0.25	0
Ancylopsetta quadrocellata	A__QUADROCEL	0	0	0	0.1	0	0
Gobiosoma longipalpa	G__LONGIPALA	0	0	0	0	0	0
Lucania parva	L__PARVA	0	0	0	4.5	0.75	0
Floridichthys carpio	F__CARPIO	0	0	0	1.3	0.25	0
Chasmodes saburrae	C__SABURRAE	0	0	0	0.3	2.5	0
Anarchopterus criniger	A__CRINIGER	0	0	0	0	1.5	0
Callinectes sapidus	C__SAPIDUS	2	0.25	3	0.1	0	0
Microgobius gulosus	M__GULOSUS	2.5	0	8	0	3.25	0
Harengula jaguana	H__JAGUANA	0	1.25	0	0.1	0	0
Eucinostomus argenteus	E__HARENGULU	0	5	0	0.5	0	0
Oligoplites saurus	O__SAURUS	0	0.25	1	1.4	0	0
Strongylura timucu	S__TIMUCU	0	0	1	0.6	0.5	0
D. *Anchoa hepsetus*	A__HEPSETUS	13	0.5	0	1.2	1.25	0
Membras martinica	M__MARTINICA	4	23.5	0	0.3	0	0
Microgobius thalassinus	M__THALASSIN	0	18	0	0	0	0
E. *Menidia spp*	MENIDIA_SPP_	0	0.75	0	27.8	0	0
Eucinostomus spp	EUCINOSTOMUS	1.5	4.25	0	3.1	37.75	0
Lagodon rhomboides	L__RHOMBOIDE	0	0	0	3.5	9.25	0

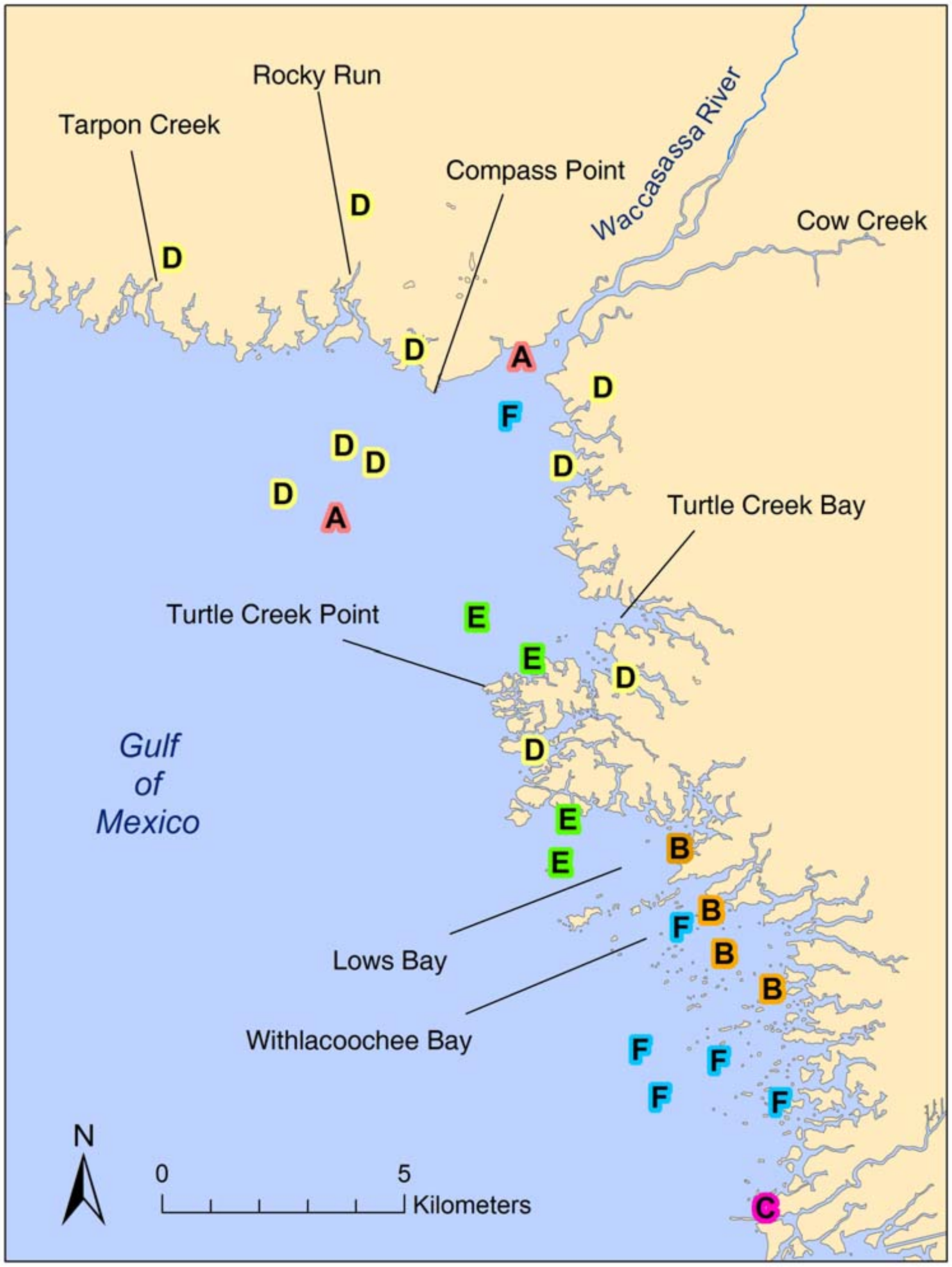


Figure 4-27. Map showing the location of nekton stations in Waccasassa Bay, July 2001, by Station Group.

PRIMER's BIO-ENV procedure (Clarke and Warwick 2001) was used as an exploratory tool to ascertain whether the community structure of the Waccasassa Bay area nekton (as Bray-Curtis similarity based upon 4th root transformed CPUE) was associated with salinity, temperature, sediment characteristics, *etc*. The objective was to find a matrix of some combination of (normalized) abiotic variables that provided a "best fit" with the multivariate structure of the nekton community in the Waccasassa Bay area. The abiotic matrix is formed by calculating Euclidean distances between all station combinations for each subset of abiotic variables tested. In Euclidean distance, stations are more similar if they are closer together in n-dimensional space than if they are further apart. If there are three abiotic variables under consideration than it is the distance in three-dimensional space; if it is five variables, than it is five-dimensional space, etc.

The statistic used to describe the degree of association is the Spearman rank correlation coefficient (ρ_s; Clarke and Ainsworth 1993). It is not appropriate to assign significance values to ρ_s values (Clarke and Warwick, 2001), and thus this approach can only be used in an exploratory manner. Prior to running the BIO-ENV procedure, PRIMER's RELATE test was used to determine whether there was a statistical relationship between the overall biotic and abiotic matrices. If there was no overall relationship than BIO-ENV would be unnecessary.

The RELATE test showed that the ranked nekton similarity matrix was similar to the ranked similarity matrix of abiotic variables (normalized water column depth, temperature, salinity, dissolved oxygen, pH, % silt+clay and sediment total organic carbon) and two variables that are related to prey availability (benthic standing crop and benthic taxa richness) at p=0.14 (Global R statistic=0.13). The exploratory BIO-ENV analysis showed that the "best" fit between the multispecies nekton similarity matrix and any combination of abiotic variables is with salinity (ρ_s=0.35) alone (Table 4-12).

Table 4-12. Summary of the association (Spearman rank correlation coefficients) between nekton community structure (Bray-Curtis similarity) and ten abiotic and biotic variables, Waccasassa Bay, July 2001: "Best fit" for combinations of 1 to 4 variables.

Number of Variables	r_s	Variables
1	0.350	Salinity
2	0.349	Salinity & % Silt+Clay
3	0.331	Salinity,% Silt+Clay & Numbers of Benthic Taxa
4	0.305	Salinity,% Silt+Clay, Depth, & Numbers of Benthic Taxa

4.6.4 Discussion

Determination of relationships between nekton and selected biotic and abiotic factors (including salinity) in Waccasassa Bay and adjacent waterbodies was constrained by having only a single, synoptic sampling event and only 27 samples. Spatial variability was observed in water column salinity, bottom sediment type, and other abiotic variables within the Waccasassa Bay area. Salinities, while predominantly >20 ppt, ranged down to <1 ppt. Both sand and mud-sized sediments were found in the study area, although mud sized sediments predominated.

The available data from this single, summer, sampling event suggested that within-bay salinity variability was related to nekton community structure. Salinity was not, however, significantly associated with any of the univariate community metrics. The general relationship was for at least three of the characteristic species (*Anchoa mitchilli, Bairdiella chrysoura*, and *Farfantepenaeus duorarum*) to be more abundant in salinities of 20 to 23 ppt than at salinities above or below that range.

Six groups of stations were identified by numerical classification analysis. These groups reflected the spatial heterogeneity of the nekton. In this analysis, relationships with hydrographic characteristics—including salinity—were generally not statistically significant. There was a statistically significant difference in water column dissolved oxygen concentrations between two of the station groups. Sediments were generally similar between the station groups. Each of the station groups had similar means for the two biological metrics linked to prey availability (total density of benthos and numbers of benthic taxa). Mean total CPUE, however, varied by approximately 200% between some of the clusters, even though the results were not statistically significant.

The relationships between preferred salinity regimens and nekton in both Waccasassa Bay and the Waccasassa River cannot, at this juncture, be quantitatively evaluated. However, inferences may be made about *general* salinity preferences for nekton in the Waccasassa Bay area and Waccasassa River by comparisons with data from other systems.

The occurrence of a number of the nekton species in the Lower Suwannee River was summarized by Williams et al. (1990), by salinity regime and time of year. Species listed in Williams et al. (1990) for the Lower Suwannee River and also relatively common in the Waccasassa Bay area included *Farfantepenaeus duorarum, Anchoa mitchilli, Lagodon rhomboides, Cynoscion arenarius* and *Cynoscion nebulosus*, and *Leiostomus xanthurus*. Tidal freshwaters (<0.5 ppt) were not particularly exploited by any of these species for any of their life stages. This salinity regime was, however, the critical year-round salinity range for juvenile and adult *Callinectes sapidus* (Williams et al., 1990).

Williams et al. (1990) identified a "mixing" class for salinity that spanned the range of 0.5 to 25 ppt. Salinities at the upper end of this range were characteristic of the Waccasassa Bay area in July 2001. Species and life stages that are dependant on this range of salinity include:

- Juvenile *Farfantepenaeus duorarum* (April-September),
- All life stages of *Anchoa mitchilli* (April-September to year round depending upon life stage), *Lagodon rhomboides* adults (February-November) and juveniles (April-September),
- All life stages of *Cynoscion nebulosus* (year-round), and
- Juvenile *Leiostomus xanthurus* (January-August).

Janicki Environmental, Inc. (2004) used logistic regression analyses to model the probability of occurrence of fish species collected by seine hauls from the Alafia River (Tampa Bay). *Anchoa mitchilli* preferred salinities of approximately 12 to 18 ppt (Figure 4-28) in the Alafia River.

Considered separately, adults preferred salinities ranging from the low 20s to approximately 30 ppt (Figure 4-28). *Bairdiella chrysoura* were most likely to be collected in salinities of 14 to 18 ppt in the Alafia River (Figure 4-29). The reported differences between salinity distributions in the vicinity of Waccasassa Bay and the Alafia River for these species may be due to differences in collection method (trawls *vs*. seines) and differences in the response variable (CPUE *vs*. occurrence).

Other fish species common in the Waccasassa Bay area that were modeled for the Alafia River included:

- *Menidia* spp. occurrence decreased as salinity increased (Figure 4-30);
- *Eucinostomus harengula* juveniles preferred 8 to 12 ppt (Figure 4-31);
- *Harengula jaguana* preferred salinities of 13 to 18 ppt (Figure 4-32);
- *Strongylura timucu* preferred salinities of 14-18 ppt (Figure 4-33);
- *Cynoscion nebulosus* (Figure 4-34) and *Symphurus plagiusa* (Figure 4-35) preferred salinities of 18 to 22 ppt;
- *Eucinostomus gula* preferred salinities are low to mid 20s (Figure 4-36); and
- The probability of occurrence of *Membras martinica* (Figure 4-37), *Leiostomus xanthurus* (Figure 4-38) and *Lagodon rhomboides* (Figure 4-39) increased as salinity increased.

The species composition of the nekton in the vicinity of Waccasassa Bay during July 2001 appears to be generally similar to that of Suwannee Sound and the Lower Suwannee River (Janicki Environmental). Salinity does appear to exert some influence on the structure of the nekton assemblage in the bay. Sediment characteristics appear to be less important.

Juvenile and adult blue crabs, *Callinectes sapidus*, are dependent upon the year-round maintenance of very low salinity (< 0.5 ppt) habitat. The majority of the fish species appear to be able to thrive over a wide range of salinities. This conclusion is based upon the July 2001 IMAP collections from Waccasassa Bay and nearby waterbodies, NOAA's (Williams et al., 1990) review of Suwannee River data, and modeling results from the Alafia River (Janicki Environmental, Inc. 2004). The July 2001 data suggest that two of the more abundant species (*Anchoa mitchilli* and *Bairdiella chrysoura*) may prefer salinities of 20 to 23 ppt over lower and higher salinities. Data collected elsewhere on salinity tolerances, however, suggest a slightly lower preferred salinity. Juvenile pink shrimp, *Farfantepenaeus duroarum*, also appears to prefer salinities in the 20 to 23 ppt range.

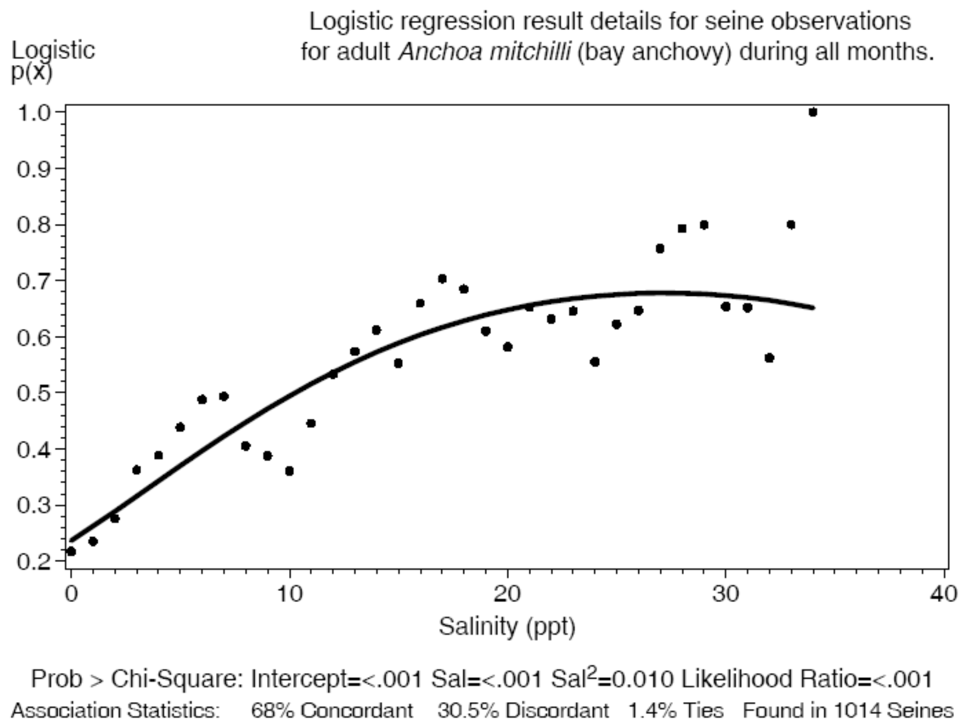


Figure 4-28 Results of logistic regression analysis depicting the probability of *Anchoa mitchilli* occurrence vs. salinity in the Alafia River (From: Janicki Environmental, Inc. 2004).

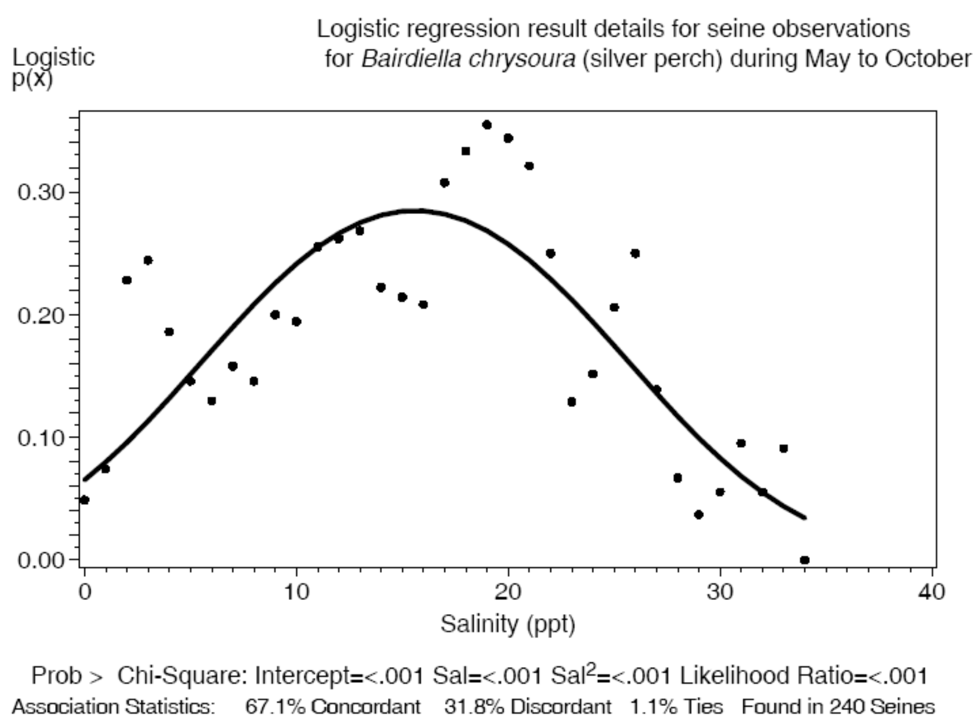


Figure 4-29 Results of logistic regression analysis depicting the probability of *Bairdiella chrysoura* occurrence vs. salinity in the Alafia River (From: Janicki Environmental, Inc. 2004).

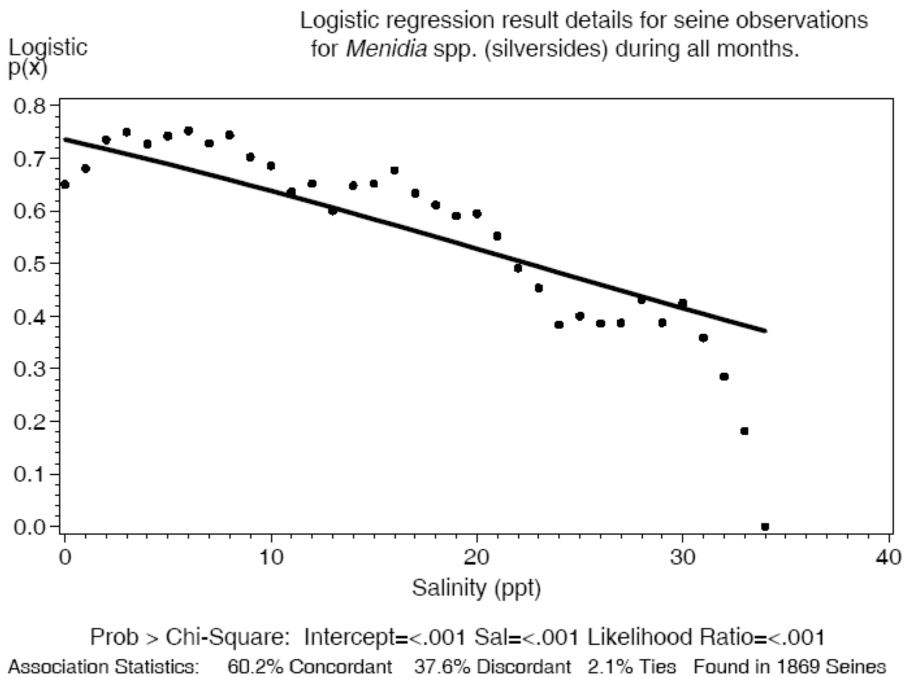
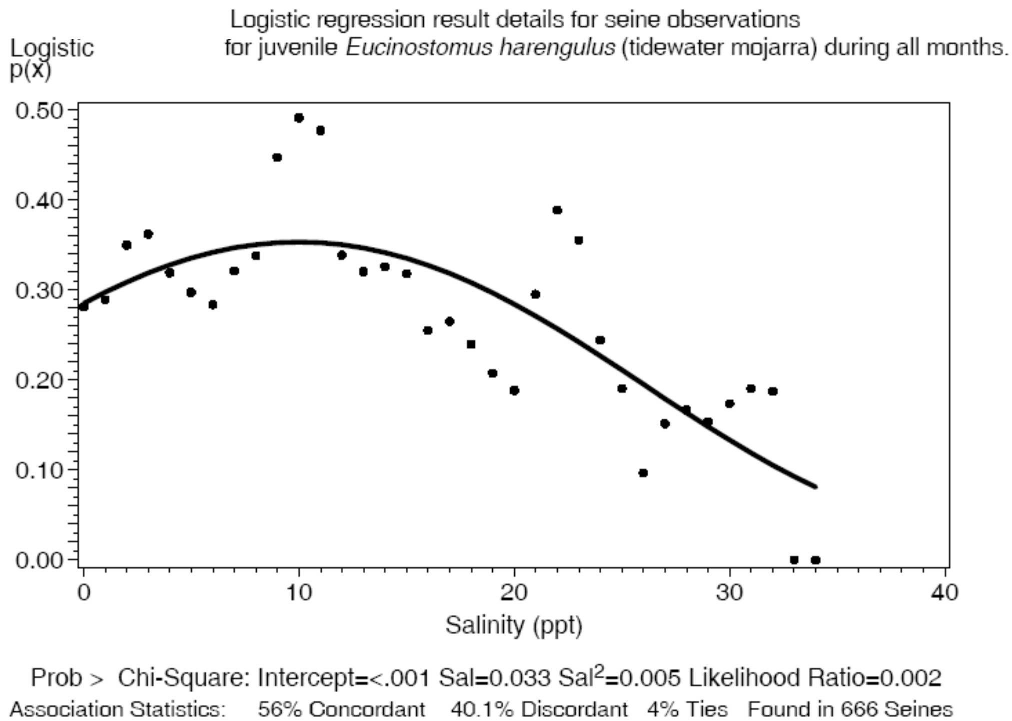


Figure 4-30 Results of logistic regression analysis depicting the probability of *Menidia* spp. occurrence *vs*. salinity in the Alafia River (From: Janicki Environmental, Inc. 2004).



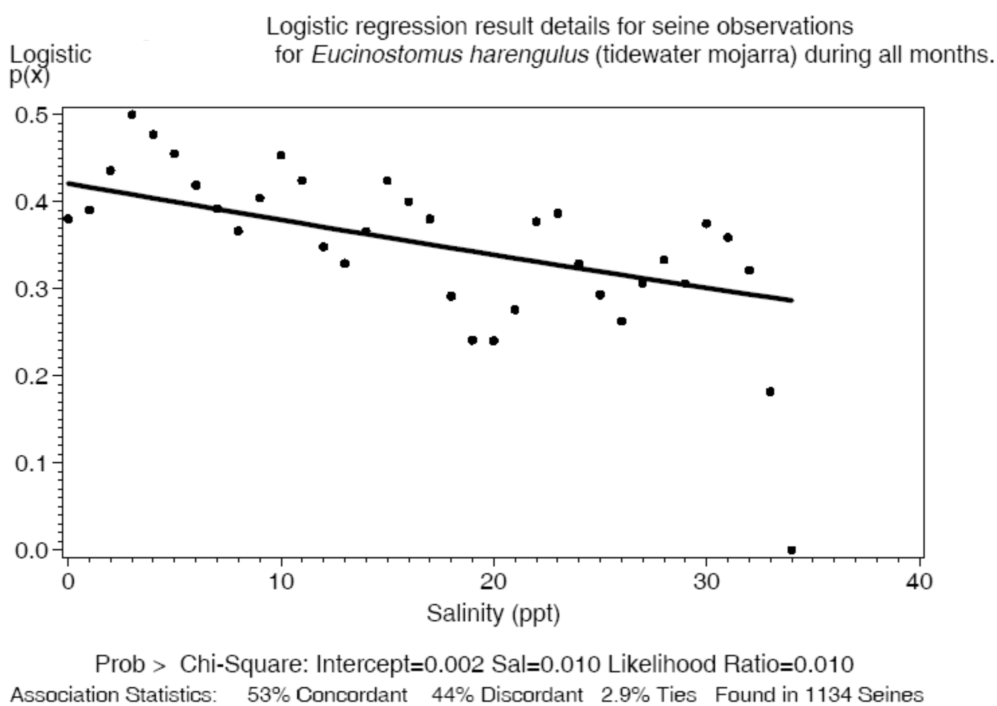


Figure 4-31 Results of logistic regression analysis depicting the probability of *Eucinostomus harengulus* occurrence *vs*. salinity in the Alafia River (From: Janicki Environmental, Inc. 2004).

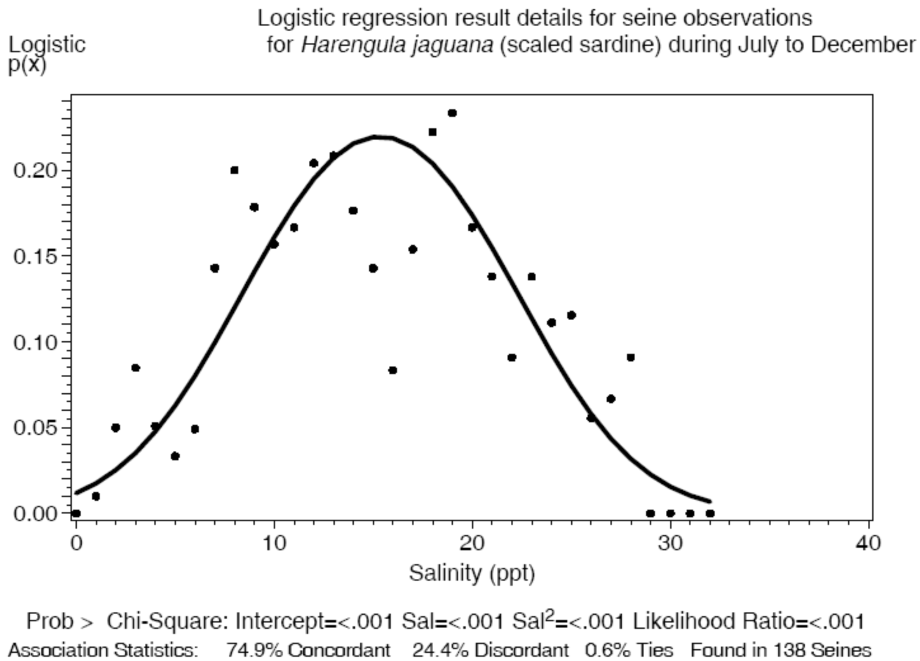


Figure 4-32 Results of logistic regression analysis depicting the probability of *Harengula jaguana* occurrence *vs*. salinity in the Alafia River (From: Janicki Environmental, Inc. 2004).

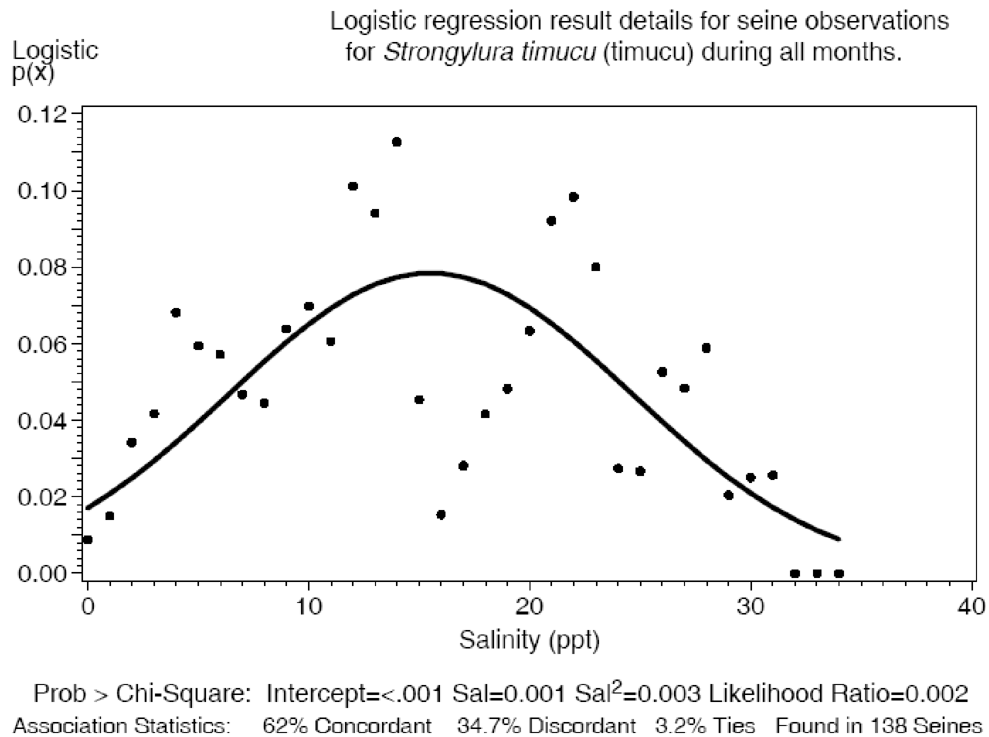


Figure 4-33 Results of logistic regression analysis depicting the probability of *Strongylura timucu* occurrence *vs*. salinity in the Alafia River (From: Janicki Environmental, Inc. 2004).

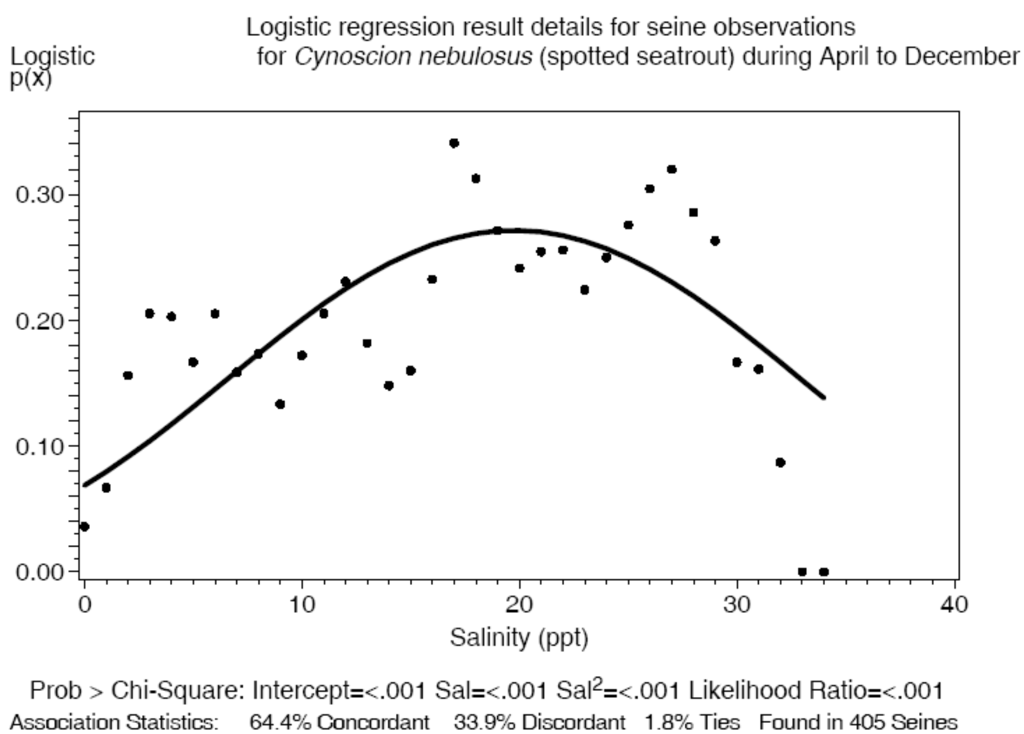


Figure 4-34. Results of logistic regression analysis depicting the probability of *Cynoscion nebulosus* occurrence *vs*. salinity in the Alafia River (From: Janicki Environmental, Inc. 2004).

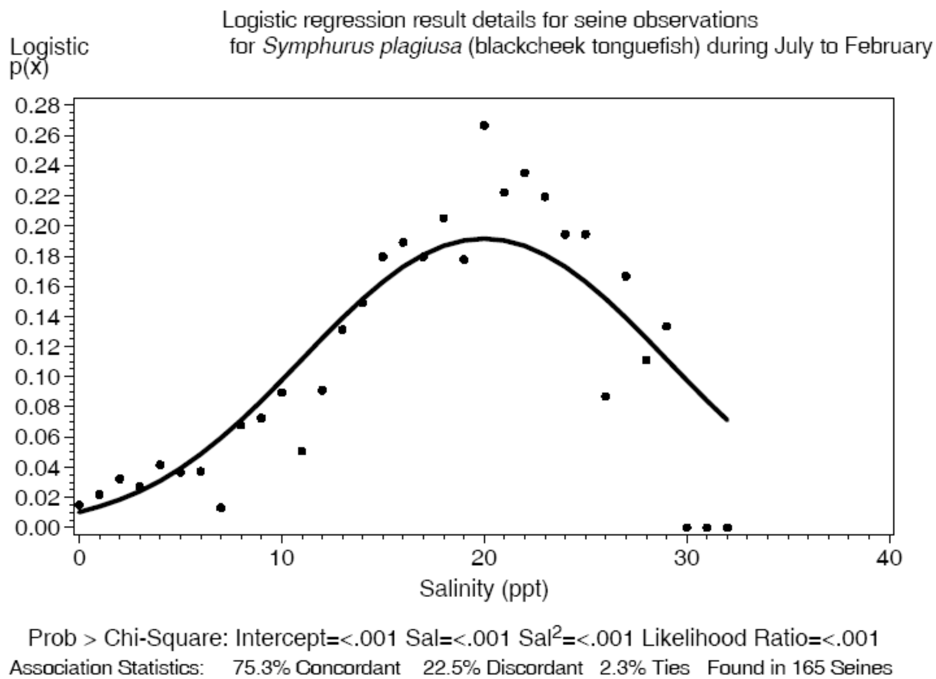


Figure 4-35 Results of logistic regression analysis depicting the probability of *Symphurus plagiusa* occurrence *vs*. salinity in the Alafia River (From: Janicki Environmental, Inc. 2004).

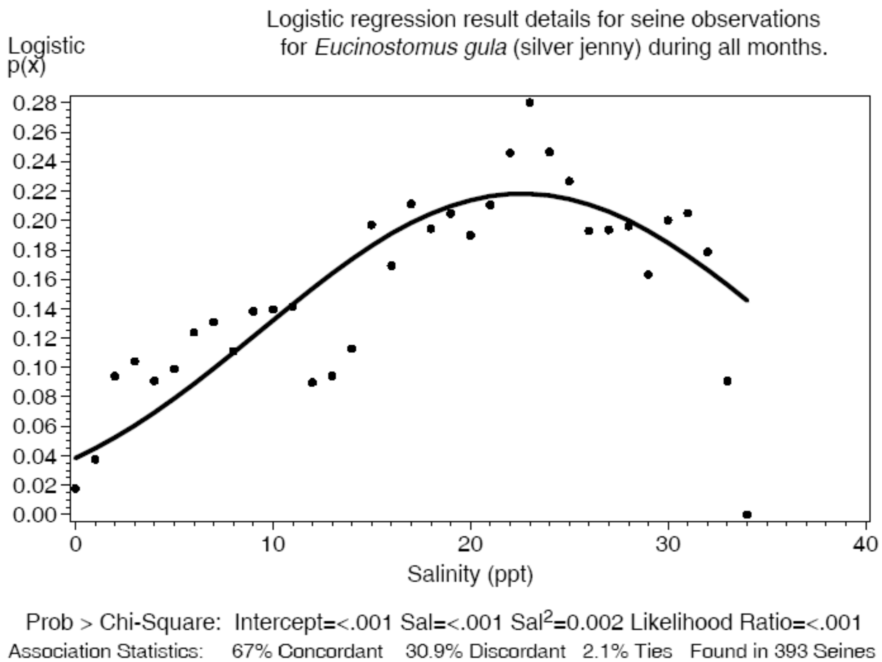


Figure 4-36 Results of logistic regression analysis depicting the probability of *Eucinostomus gula* occurrence *vs*. salinity in the Alafia River (From: Janicki Environmental, Inc. 2004).

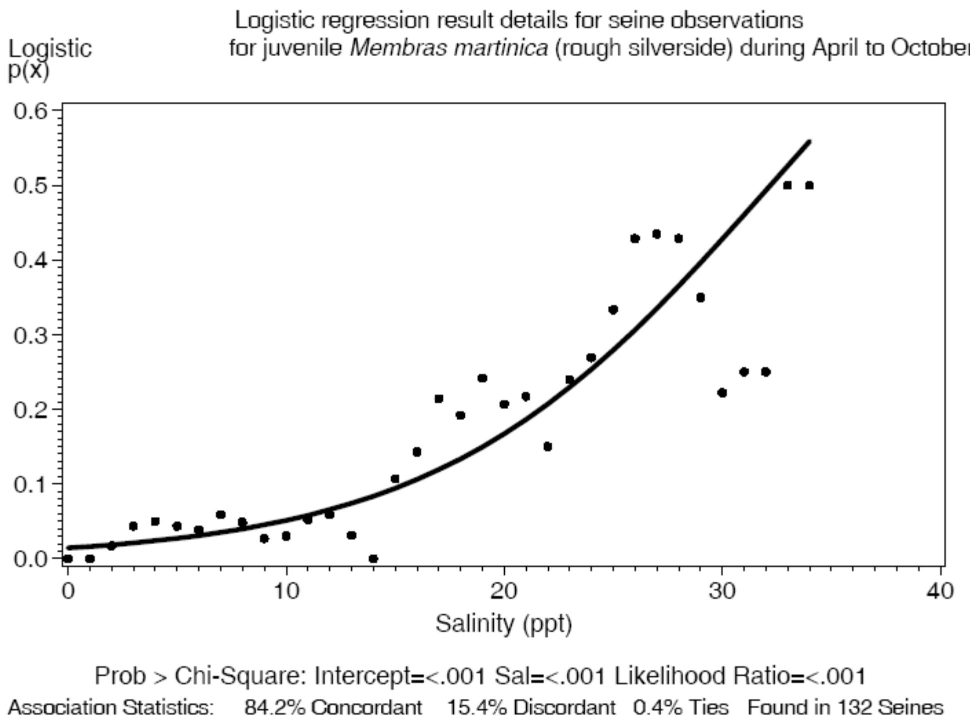


Figure 4-37 Results of logistic regression analysis depicting the probability of *Membras martinica* occurrence *vs*. salinity in the Alafia River (From: Janicki Environmental, Inc. 2004).

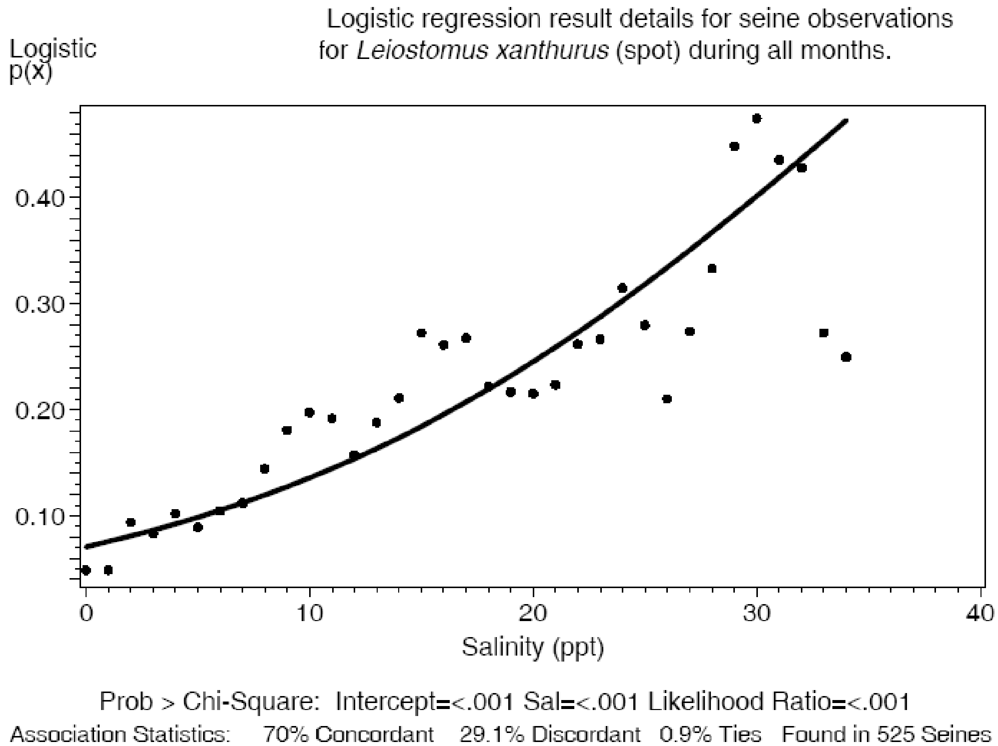


Figure 4-38 Results of logistic regression analysis depicting the probability of *Leiostomus xanthurus* occurrence *vs*. salinity in the Alafia River (From: Janicki Environmental, Inc. 2004).

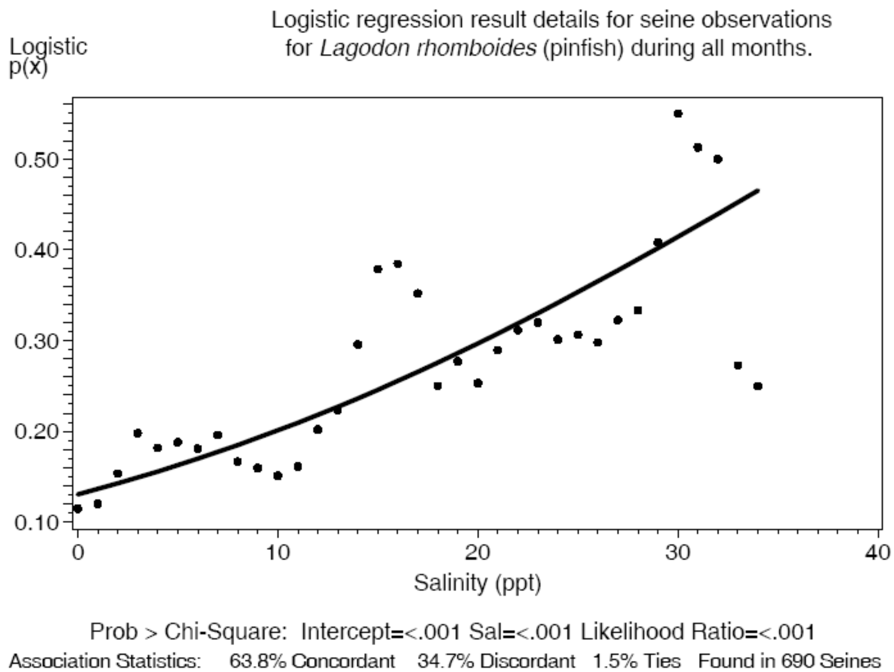


Figure 4-39 Results of logistic regression analysis depicting the probability of *Lagodon rhomboides* occurrence *vs*. salinity in the Alafia River (From: Janicki Environmental, Inc. 2004).

TAB 5

5.0 Establishment of MFLs for the Waccasassa River System

This section presents the rationales for the proposed MFLs for the Waccasassa River and Levy Blue Spring. The process for MFL selection applies a data driven approach to identifying a potential MFL by using empirical data to the greatest extent possible to identify relationships between freshwater inflows, salinities and biotic habitats of concern with respect to protecting valued resources within the Waccasassa River system. All the available information from the river was assessed to arrive at an MFL recommendation using a “weight of evidence” approach. In this process, considerations were given to the effects of variation in freshwater inflow on water quality, benthic macro-invertebrates, nekton, and shoreline vegetative communities associated with the Wacasassa River and Waccasassa Bay. Human use components are also evaluated as part of the MFL selection process. The final recommended MFL represents the most robust and scientifically defensible of all the considered criteria used in the MFL selection process.

5.1 Salinity-Flow Habitat Relationships: Establishment of an MFL for the Waccasassa River

Fresh water inflows have direct and indirect effects of biological resources. Direct effects of freshwater inflow include changes in stream velocity and water chemistry, which in turn affect the suitability of the environmental for utilization by biological resources (i.e., an indirect effect of flow). The Waccasassa River represents a relatively undisturbed watershed. No known species of special concern, such as threatened or endangered species, are reported to rely directly on the Waccasassa River. The following summarizes the results of analysis of the biota detailed in section 4 with respect to its relevance in the MFL selection process.

5.1.1 Benthos

Janicki Environmental, Inc. (2005) analyzed the relationship between benthos and bottom salinity from 12 southwest Florida tidal rivers. These analyses showed that four different benthic communities could be demarcated based upon the bottom salinity regime. The benthic community characteristic of the least saline (0 to 7 ppt) salinity class is of particular importance with respect to setting an MFL for the Waccasassa River.

The very limited benthic data that are available for the Waccasassa River show that there is an assemblage characteristic of lower salinity waters. Twenty-four of the 67 taxa that were identified from the three river stations are fresh-water or tolerant of very low salinities (*e.g.*, chironomid larvae, some oligochaetes; Culter 1986). Numerical dominants in the river included the tanaid *Halmyrapseudes bahamensis*, the amphipod *Cerapus benthophilus*, and the polychaete *Amphicteis gunneri.*

Regionally, the benthic community characteristic of the 0 to 7 ppt salinity range within southwest Florida tidal rivers class included chironomid larvae, tubificid oligochaetes, and the polychaete *Laeonereis culveri* (Table 5-1)—taxa that are reported from the Waccasassa River. It is reasonable to expect that, given a more robust sampling regimen than the sampling of just three locations during a single month, many more of the benthic macro-invertebrates characteristic of this low salinity zone would be collected.

Table 5-1 Similarity percentage analysis of Southwest Florida tidal river benthos: community structure (presence-absence) within the 0-7 ppt salinity classes. Benthic taxa explaining at least 90% of the cumulative within-group similarity are listed. *= taxa reported from the Waccasassa River

Species	Percent Occurrence	Percent Contribution to the Overall Similarity within this Salinity Class
* *Laeonereis culveri*	0.36	23.3
*Tubificidae	0.27	14.4
* *Polypedilum scalaneum*	0.23	9.5
Chironomus sp.	0.18	6.5
* Hydrobiidae	0.14	5.3
Mytilopsis leucophaeata	0.17	5.1
* *Grandidierella bonnieroides*	0.20	5.0
* *Polypedilum halterale*	0.16	4.8
Cyathura polita	0.16	3.8
*Oligochaeta	0.10	3.1
* *Streblospio gynobranchiata*	0.14	2.8
* Nemertea	0.13	2.6
Stenoninereis martini	0.11	2.3
* *Limnodrilus hoffmeisteri*	0.11	2.2

In terms of the benthic analyses presented in Section 4.0, Figure 4-18 shows the clustering of a riverine group of benthos (i.e., Group A), a lower riverine, upper bay group (i.e., Group C), a tidal creek group (i.e., Group B), and several clusters of bay assemblages. Based on limited data, which constrained the development of quantitative relationships, it is apparent that a gradient of bottom salinity conditions including a low salinity regime will ensure habitat for the different benthic assemblages outlined in Section 4.0.

5.1.2 Nekton

Additionally, analysis conducted on tidal creek nekton assemblages in the Lower Suwannee River yielded the salinity classes seen in Figure 4-25. These salinities were depth integrated (vertically averaged) to include the salinities encountered by fish collected throughout the water column. The lower salinity, tidal, fish assemblage inhabited salinities between 1 and 6 ppt. Two species shown to prefer this low salinity habitat (in a study conducted on the Alafia River) were tidewater mojarras and silversides (Figures 4-31 and 4-30, respectively). The data on fish were restricted to Waccasassa Bay, which limited the amount of data that was available for salinities less than 6 ppt. Dominant species were reported to inhabit a wide range of salinity conditions, most notably the higher salinities found in the bay samples. Therefore, very limited information was directly available to quantitatively assess direct relationships between fresh water inflows and fishes in the Waccasassa River. However, low salinity habitat is known to be important for the development of larval and juvenile estuarine-dependent fish, which use low salinity tidal creeks and marsh habitats as nursery and foraging grounds Rozas and Hackney, 1983; Comp and Seaman, 1985).

5.1.3 Shoreline vegetative

Information on vegetation along the Waccasassa River shoreline, including delineations of major vegetative habitat types and qualitative data provided during field observations during the 2005 salinity study was available for use in establishing a recommended MFL. Based on the vegetative studies detailed in Section 4, the upstream end of Stafford Island appears to separate a more saline estuarine environment characterized by marsh vegetation from the lower salinity oligohaline marsh found upstream. Oligohaline marsh habitat, such as that located upstream of Stafford Island in the Waccasassa, has been identified as a "priority habitat target" for conservation in the northern Gulf of Mexico (Beck and others, 2000). Therefore, the distribution of emergent vegetation in the Waccasassa River should be indicative of the long-term surfacewater salinity distributions in the river. Supporting evidence includes observations that diversity in shoreline-oriented vegetation increased with movement upstream in the Waccasassa (Mote and Mangrove, 1986).

5.1.4 Summary

To protect both macro-invertebrates and nekton that require lower salinity habitat, as well as ensure emergent vegetation community diversity, the MFL should be sufficient to maintain a persistent low salinity isohaline that protects oligohaline habitat, including the oligohaline marsh vegetation. Such a MFL would protect low salinity habitat necessary as a nursery area for juveniles of estuarine fish species, many of which are commercially or recreationally important, allow for low salinity habitat to exist to maintain benthic productivity and also protect vegetative diversity in the Waccasassa. In the Waccasassa River, several lines of evidence point to a vegetative transition zone between river kilometer (rkm) 5 and 6. Vegetative mapping and field observations characterize rkm 5.6 as the downstream limit of reasonable quality tidal swamp and coastal forest with infringing Black Rush. A surface salinity of 5 ppt generally defines the upper range of this oligohaline vegetative habitat (Odum et al., 1984).

5.2 Approach and Rationale

Using the information gathered through analysis of the biotic community in the Waccasassa, the analytical approach used to determine the recommended MFL was to quantitatively asses the direct effects of fresh water inflow on salinity and determine potential risk of significant harm to the biotic communities based on upstream incursions of salinity.

The available information on salinity was gathered and reviewed, and available salinity data were coupled with flow data to generate the location of several isohalines in the system. Specifically:

- linear interpolation was used to identify the following isohaline locations: 1 to 10 ppt, 12 ppt, and 15 ppt. Isohaline locations are important as they identify the locations (in river kilometers) and extent of available habitat within specific salinity regimes.
- Regression analysis was used to develop predictive equations which could be used to estimate the location of various isohalines as a function of fresh water inflow in the Waccasassa River.
- Predicted isohaline positions in the estuary were related to known information on habitat requirements of valued biotic communities utilizing the Waccasassa River
- A MFL was recommended to protect these biotic communities from risk of significant harm

5.2.1 Description of Salinity Studies in the Waccasassa River System

The tidal characteristics of the estuarine portion of the Waccasassa River have been characterized by Stelzenmuller (1965) and by Mote Marine Laboratory (Dixon, 1986). Generally, the estuarine portion of the Waccasassa River was characterized as a well-mixed system, largely influenced by daily tidal cycles with little apparent vertical stratification (i.e. < 5 ppt). Data related to estimating the effects of freshwater inflows on the salinity characteristics of the estuarine portion of the river were limited to two studies: the 1985 study by Mote Marine

Laboratory (Dixon, 1986) for SWFWMD and another synoptic salinity survey conducted in late 2004 and 2005 under the direction of the SRWMD (SRWMD/WAR, 2005). In each of these studies monthly sampling was conducted by collecting vertical salinity profiles in one-meter intervals at fixed locations within the Waccasassa River and extending into Waccasassa Bay (Figure 5-1).

A USGS stage and velocity recorder located at Gulf Hammock above the Otter Creek confluence (29^{O}12'14"N, 82^{O}46'09"W) has been in operation since 1963. The flow at Waccasassa River near Gulf Hammock (USGS 02313700) corresponds to the dates when salinity surveys were conducted (Table 5-2). Since 1996, SRWMD gages located within the Waccasassa River upstream of tidal influence have recorded flows at Wekiva Springs near Gulf Hammock (USGS 02313600), Waccasassa River at Gulf Hammock at US 19 (USGS 02313530), and Ten Mile Creek at Lebanon Station (USGS 02314200) (see Section 3).

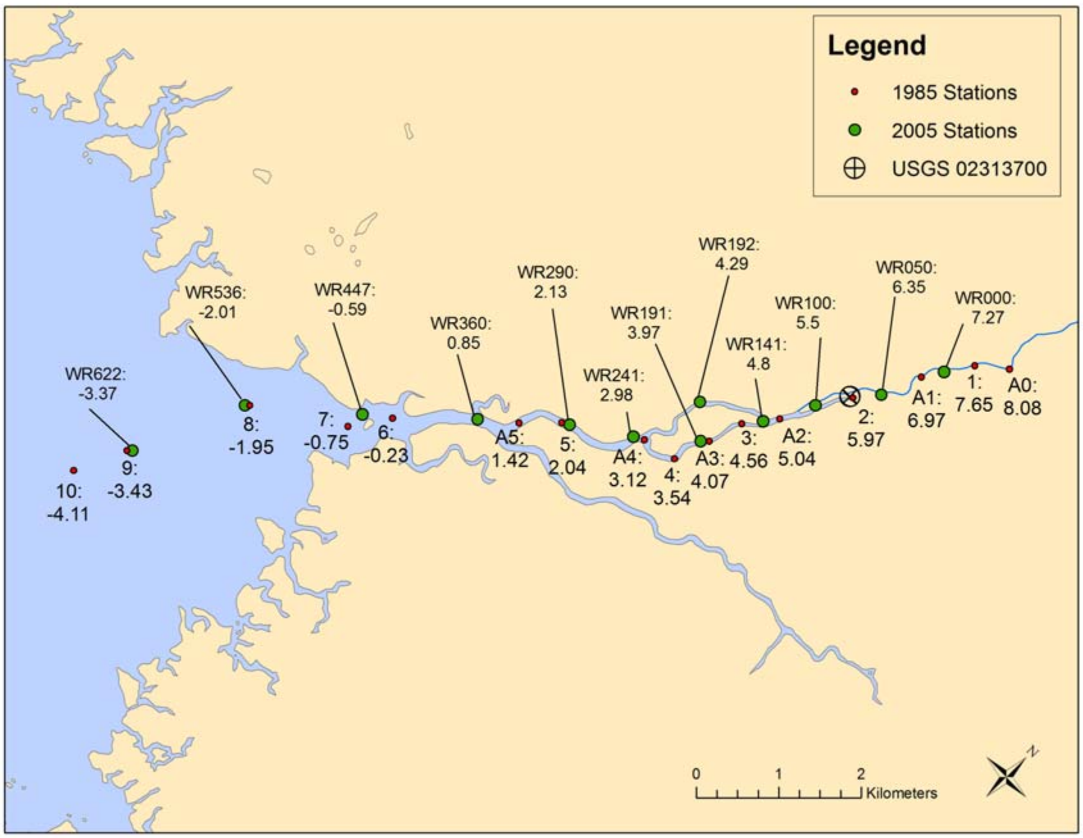


Figure 5-1 Fixed location sampling sites for the 1985 (Mote) and 2005 (SRWMD/WAR) synoptic salinity surveys in the Waccasassa River. A corresponding river kilometer (rkm) system is identified for each station (i.e. station name or number: river kilometer).

Table 5-2 Flow at USGS 02313700 (Gulf Hammock) gage corresponding to dates on which salinity measurements were recorded in the Waccasassa River and Waccasassa Bay.

Waccasassa 1985 Salinity Survey		Waccasassa 2005 Salinity Survey	
Date	Daily Mean Flow at USGS 02313700 (cfs)	Date	Daily Mean Flow at USGS 02313700 (cfs)
Feb/05/1985	53	Oct/26/2004	467
Apr/17/1985	504	Nov/29/2004	295
May/23/1985	-17	Dec/29/2004	265
Jun/11/1985	55	Jan/24/2005	158
Jun/20/1985	99	Feb/28/2005	304
Jul/22/1985	382	Mar/21/2005	184
Jul/31/1985	283	Apr/14/2005	574
Aug/11/1985	273	May/19/2005	192
Sep/13/1985	656	Jun/23/2005	510
Oct/23/1985	125	Jul/20/2005	626
Dec/08/1985	13		

The two synoptic salinity surveys represent relatively different hydrologic periods for Wacasassa inflows. The 1985 data incorporate periods of a drought and drought recovery. The 2005 data were collected at a time when the flows were normal to slightly above normal relative to the long term median for the period of record (*i.e.,* 157 cfs; Figure 5-2).

The salinity regime represented a typical pattern indicative of a tidally influenced river with Waccasassa Bay samples averaging 15 to 25 ppt and decreasing salinity with progression into the river and upstream. Higher average salinities were observed in 1985 relative to 2005 illustrating the effects of reduced flows on salinities at these fixed locations (Figure 5-3). The 1985 dataset included a notation for tidal stage (i.e., ”high” or “low”). For data collected in 2005, sample date and time were chosen “haphazardly” and time and tidal stage was recorded. Sampling events commenced at the most upstream station, progressed downstream to the most seaward station, and then sampled upstream en route to the initial sampling location. Preliminarily, samples taken closer to “high” tide were assigned the high tide value while those taken closer to low tide were assigned a designation of “Low tide”.

Only samples with the designation of high tide were used in the regression analysis to estimate the maximum upstream incursions under normal conditions. Thereby, the regression relationships represent a conservative estimate of the salinity to which the biota is exposed at high tide. The variable which recorded tidal stage information in the 2005 data was later used in the analysis to correct the 2005 salinity data to its value at high tide in an attempt to combine the 1985 and 2005 datasets. This approach is described in detail in the analytical methods section and in the section describing the establishment of the MFL.

5.2.2 Analytical Methods

Isohaline locations in the Waccasassa River and Bay were assessed using linear interpolation. Interpolated isohaline locations were established for the 1 to 10 ppt, 12 ppt, and 15 ppt isohalines. Initially, isohaline locations were developed for surface, bottom and depth integrated salinity. Depth-integrated salinity averages all salinity values taken as a vertical profile for each sample location. For each date and sample depth the 5 ppt isohaline position was calculated by selecting the fixed locations that immediately bracketed a salinity of 5 ppt. To calculate the exact position of the isohaline, a slope was calculated that defined the rate of change in salinity between the two fixed location stations that bracketed the 5 ppt isohaline and the location was thereby estimated. Once the isohaline data were established in this way for each sampling event, linear regression was used to relate each isohaline position to freshwater inflow. There were a few cases where a particular isohaline was not observed, such as when the 1 or 2 ppt isohaline was upstream of the most upstream measurement station (Station A0, Figure 5-1). In this case, that particular isohaline was not calculated for the sampling event, reducing the number of observations for that particular isohaline.

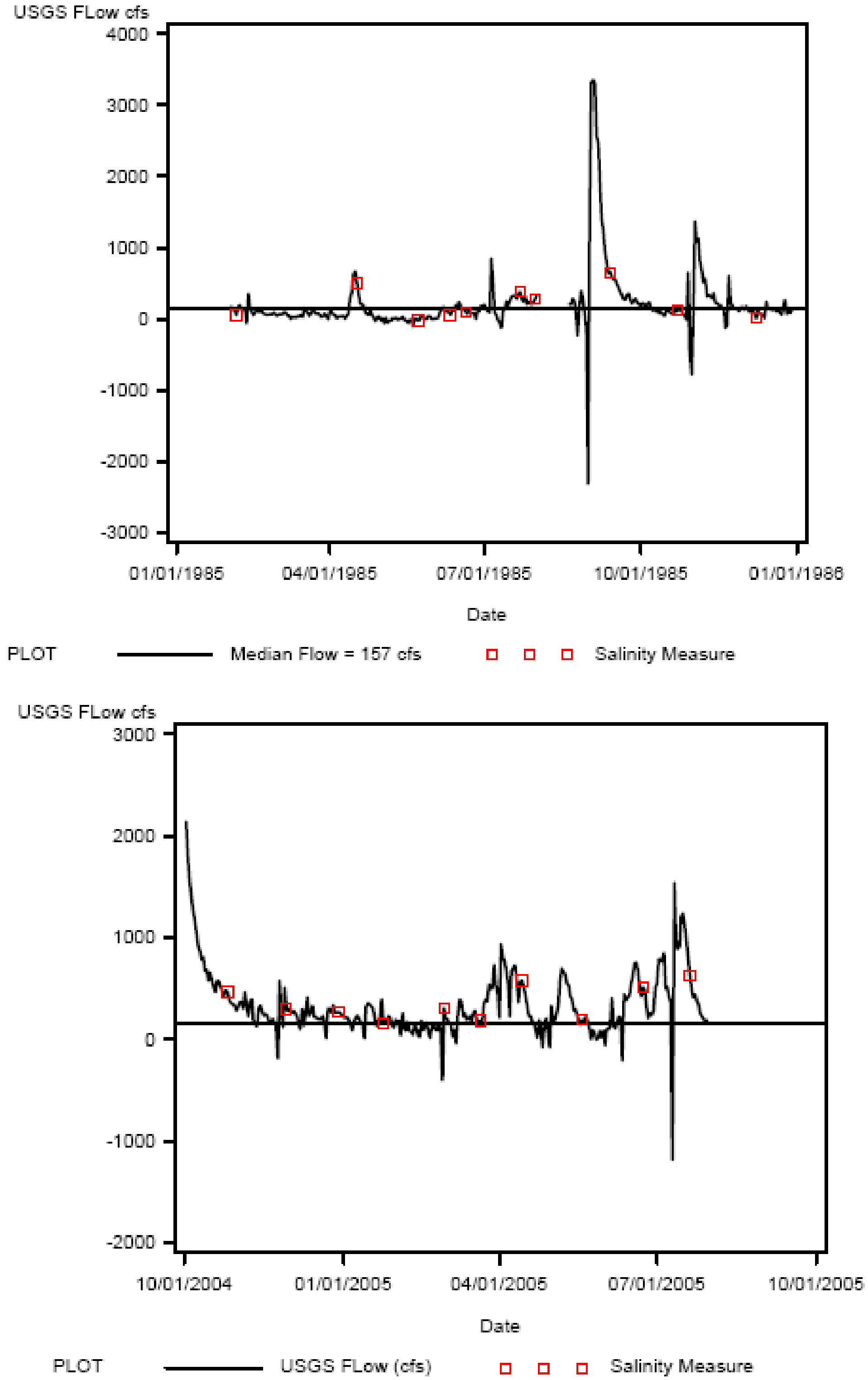


Figure 5-2 Flow time series for the USGS 02313700 gage, over the period of 1985 corresponding to the synoptic salinity survey (top) (source: SWFWMD/Mote, 1985) and the 2005 data (bottom) (source: SRWMD/WAR, 2005) with salinity sampling dates marked as a red square. The horizontal line represents the long-term median flow of 157 cfs at USGS 02313700 (Gulf Hammock).

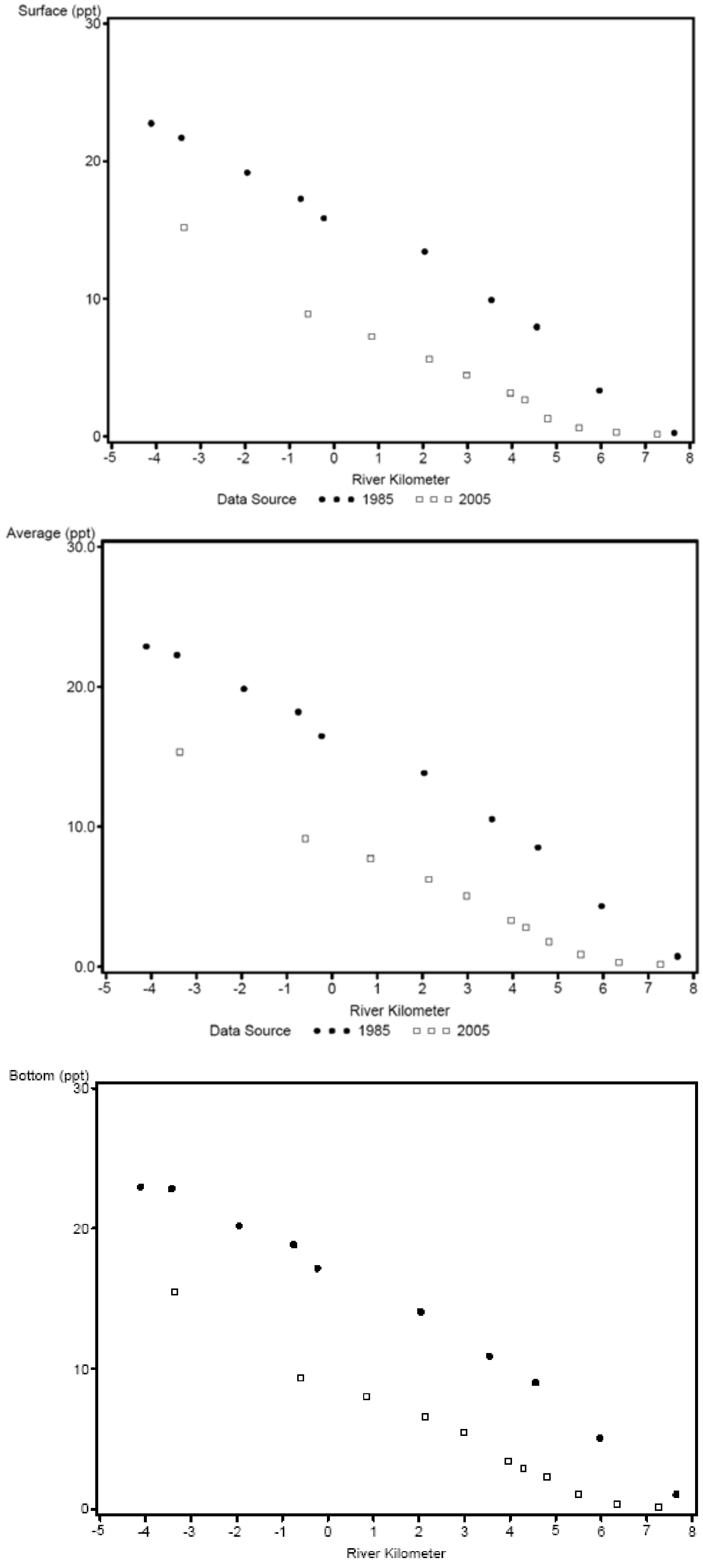


Figure 5-3 The overall average surface (Top), depth integrated (Middle), and bottom (Bottom) salinity for each consistently sampled fixed location station. Values are plotted against river kilometer for the data collected in 1985 (dot) and 2005 (open square).

Univariate regression relationships between flow and isohaline location were initially derived independently for the 1985 and 2005 data collected at high tide using the equation:

$$\hat{I} = B_0 + B_1 * Discharge$$

Here:

$\hat{I}$ = Predicted isohaline location,
B_0 = intercept, and
B_1 = Coefficient describing rate of change in isohaline location per unit change in discharge.

For the data collected in 1985, the only discharge data available were from the USGS gage at Gulf Hammock; therefore, the discharge data from this gage were used to predict isohaline location for the 1985 data. Antecedent flows up to 7 days as well as lag averaged flow to 7 days were considered using a stepwise regression approach to select the best predictor of isohaline location using data from the Gage at Gulf Hammock. Only when an antecedent flow condition made a significant improvement in the model fit (>5% increase in rsquare) over the prediction using the sample dates flow value was the antecedent flow used in the final regression equations.

In 1996, The SRWMD established additional flow gages that provided data in addition to the data from the USGS gage at Gulf Hammock. Therefore, prediction of isohaline locations using the 2005 data was performed using the USGS gage as a predictor variable and also using data from the three gages operated by SRWMD. A cumulative discharge term (Sumflow) was calculated by summing the discharge measurements from Ten Mile Creek, US 19, and Wekiva Spring gages each day to serve as a proxy for the total inflow into the Waccasassa River. Antecedent flows were again evaluated using stepwise selection criteria and again were only included in the results when they significantly improved the estimated relationship over the prediction using the sample dates flow value.

Since few samples from the 2005 data were taken at reduced flows (*i.e.*, flows below the long term median), the data collected around high tide in 1985 was combined with the 2005 data collected around high tide. This increased the robustness of the estimate of the relationship between fresh-water inflow and isohaline location over a broader range of estuarine flow conditions than either study could provide independently. In order to combine data from the two salinity surveys in the Waccasassa, the isohaline position in the 2005 data was adjusted to its predicted location at high tide by estimating the effect of tide height on isohaline location. The variable TIDEFT indicating the tide height at time of sampling was used to predict the effect of tide height on isohaline position. The difference between the tide height at time of sampling and tide height at high tide was then calculated and the regression coefficient multiplied by the difference to adjust the data. The assumption for this correction is that the isohaline location is a function of flow and tide height (i.e., if flow is held constant, the isohaline position responds to tide height regardless of where in the tidal cycle that tide height is measured). A detailed description of this adjustment for the 5ppt isohaline is provided in the results section on pages 5-15 through 5-17.

Once the discharge / isohaline relationships were established using the steps described above, the discharge rate (cfs) necessary to protect the ecological integrity of important biological estuarine resources with the estuary was estimated.

5.3 Results

5.3.1 Univariate Regression Results

Isohaline location varied as a function of flow in both studies (Figure 5-4). Note that in the 1985 study the range for the lower isohalines (*i.e.*, 1 to 5 ppt) appeared to be truncated relative to the higher isohalines reflecting times when the actual position of the isohaline was upstream of the most upstream station measured. Therefore, this resulted in the number of measurements available for that date being reduced. The effects of higher inflows in the 2005 study reduced this effect for the 2005 data.

Regression relationships were successfully developed using the USGS 02313700 discharge gage for most isohalines in both the 1985 and 2005 studies (Tables 5-3 and 5-4). There was not a significant improvement in the regression results using antecedent conditions or, for the 2005 data, using alternative gauging stations. For the 2005 study, data from two dates (10/26/04 and 7/20/05) were classified as outliers and omitted from the analysis. These observations had extremely high salinity isohaline locations relative to the recorded discharge at Gulf Hammock likely due to strong wind set ups from a westerly direction driving estuarine waters into the river (Appendix E-1).

It should be noted that the average isohaline locations are potentially farther upstream on the bottom than on the surface, a result of gravitational residual circulation.

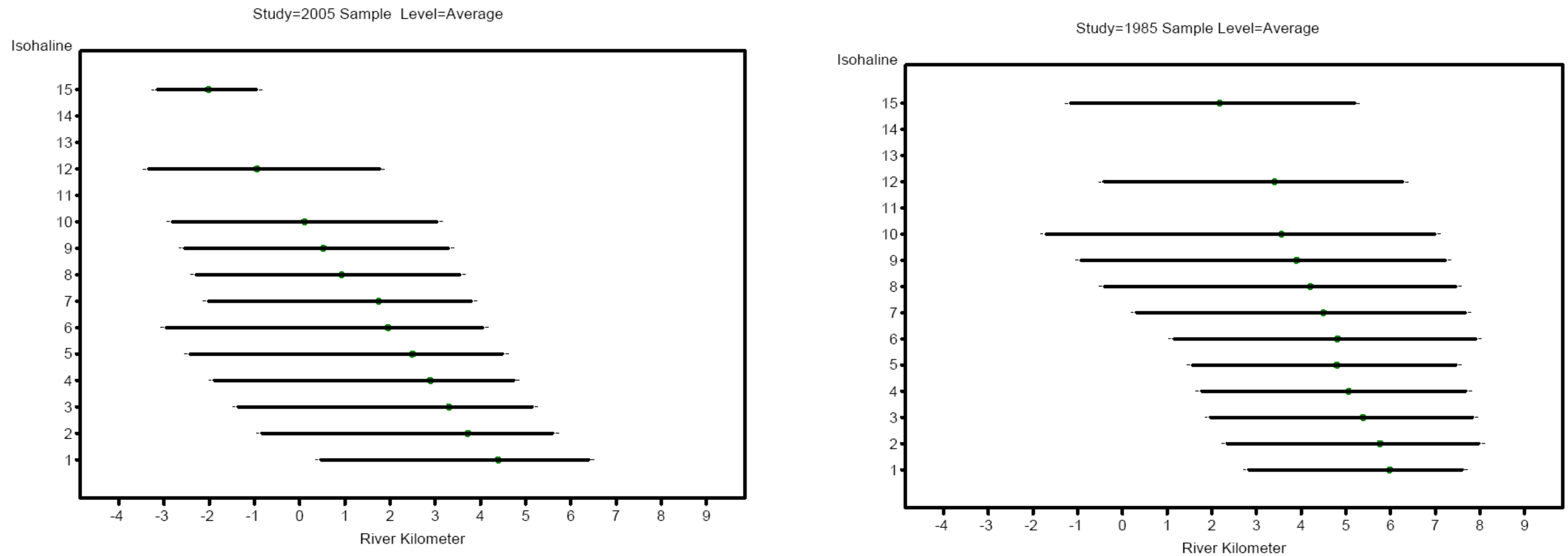


Figure 5-4 Average location (dot) and range (bar) for each of the tested isohalines in the Waccasassa River for the 2005 study (left) and 1985 study (right).

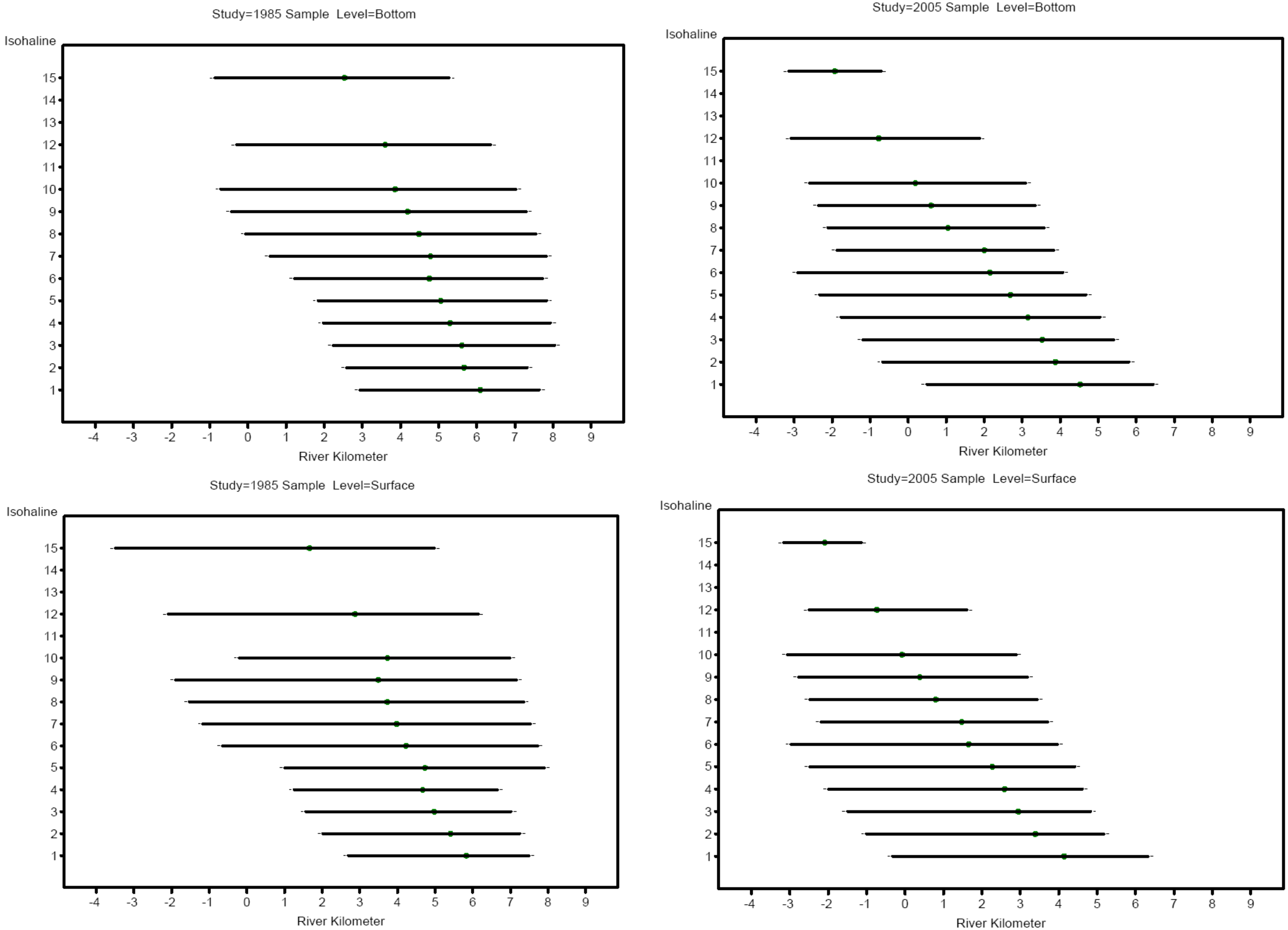


Figure 5-4 (continued) Average location (dot) and range (bar) for each of the tested isohalines in the Waccasassa River for the 1985 study (left) and 2005 study (right).

Table 5-3 Results of univariate linear regression using discharge at USGS 02313700 to predict isohaline location within the estuary at high tide. Salinity data collected by Mote/SWFWMD (1985). EDF = error degrees of freedom, RSQ = coefficient of determination.

Isohaline	Sample level	EDF	Intercept	Slope	P_value	RSQ
1	Average	6	7.77748	-0.007148	0.007325	0.67890
1	Bottom	6	7.91926	-0.007282	0.004829	0.71900
1	Surface	7	7.38022	-0.006764	0.007546	0.61485
2	Average	7	7.45379	-0.007365	0.005912	0.63959
2	Bottom	6	7.39222	-0.006880	0.009481	0.65143
2	Surface	7	6.99863	-0.006930	0.012771	0.55605
3	Average	7	7.05308	-0.007262	0.007156	0.62035
3	Bottom	7	7.32247	-0.007480	0.004771	0.66009
3	Surface	7	6.53292	-0.006793	0.011855	0.56484
4	Average	7	6.70599	-0.007179	0.007394	0.61696
4	Bottom	7	7.03000	-0.007536	0.005647	0.64406
4	Surface	7	6.23998	-0.006852	0.008728	0.59934
5	Average	7	6.48003	-0.007340	0.005797	0.64151
5	Bottom	7	6.80961	-0.007654	0.004960	0.65646
5	Surface	8	6.31396	-0.007742	0.002551	0.66230
6	Average	8	6.60245	-0.008753	0.001002	0.73054
6	Bottom	7	6.65096	-0.008258	0.003023	0.70011
6	Surface	8	6.29526	-0.010122	0.000320	0.79606
7	Average	8	6.42643	-0.009431	0.000567	0.76539
7	Bottom	8	6.67341	-0.009236	0.000735	0.75009
7	Surface	8	6.09434	-0.010353	0.000381	0.78713
8	Average	8	6.23128	-0.009903	0.000441	0.77928
8	Bottom	8	6.43191	-0.009516	0.000617	0.76045
8	Surface	8	5.88011	-0.010511	0.000524	0.76990
9	Average	8	5.97042	-0.010124	0.000575	0.76459
9	Bottom	8	6.17092	-0.009687	0.000712	0.75200
9	Surface	8	5.68130	-0.010714	0.000667	0.75587
10	Average	8	5.72835	-0.010609	0.000598	0.76228
10	Bottom	8	5.83916	-0.009674	0.001115	0.72348
10	Surface	7	5.31368	-0.010233	0.017089	0.52010
12	Average	7	4.83347	-0.009288	0.015882	0.52938
12	Bottom	7	5.06829	-0.009514	0.014436	0.54123
12	Surface	7	4.55444	-0.010906	0.039696	0.40121
15	Average	7	3.77520	-0.010356	0.023498	0.47783
15	Bottom	7	4.00710	-0.009550	0.017893	0.51419
15	Surface	7	3.46476	-0.011662	0.037012	0.41196

Table 5-4 Results of univariate linear regression using discharge at USGS 02313700 to predict isohaline location within the estuary using data designated as collected within 2 hours of high tide. Salinity data collected by WAR/SRWMD (2005). EDF = error degrees of freedom, RSQ = coefficient of determination

Isohaline	Sample level	EDF	Intercept	Slope	P_value	RSQ
1	Average	6	7.9855	-0.0129	0.0032	0.7886
1	Bottom	6	7.9278	-0.0123	0.0044	0.7660
1	Surface	6	8.1498	-0.0142	0.0024	0.8084
2	Average	6	8.1370	-0.0157	0.0009	0.8604
2	Bottom	6	8.2642	-0.0156	0.0013	0.8437
2	Surface	6	7.7184	-0.0153	0.0007	0.8686
3	Average	6	7.7847	-0.0158	0.0007	0.8716
3	Bottom	6	8.0366	-0.0160	0.0008	0.8649
3	Surface	6	7.2455	-0.0153	0.0011	0.8498
4	Average	6	7.3440	-0.0158	0.0008	0.8630
4	Bottom	6	7.7265	-0.0162	0.0008	0.8638
4	Surface	6	6.9051	-0.0154	0.0018	0.8243
5	Average	6	6.9848	-0.0160	0.0010	0.8553
5	Bottom	6	7.2290	-0.0161	0.0010	0.8564
5	Surface	6	6.6391	-0.0157	0.0026	0.8030
6	Average	6	6.5306	-0.0160	0.0007	0.8729
6	Bottom	6	6.7598	-0.0161	0.0005	0.8823
6	Surface	6	6.1099	-0.0156	0.0007	0.8736
7	Average	5	5.3495	-0.0137	0.0161	0.7180
7	Bottom	5	5.6511	-0.0138	0.0123	0.7454
7	Surface	5	4.9515	-0.0133	0.0246	0.6689
8	Average	5	4.1555	-0.0121	0.0757	0.4998
8	Bottom	5	4.2144	-0.0118	0.0819	0.4855
8	Surface	5	4.1174	-0.0126	0.0591	0.5423
9	Average	5	3.6589	-0.0116	0.1003	0.4475
9	Bottom	5	3.6833	-0.0113	0.1131	0.4240
9	Surface	5	3.5827	-0.0120	0.0760	0.4991
10	Average	5	3.2131	-0.0112	0.1217	0.4093
10	Bottom	5	3.2727	-0.0110	0.1324	0.3922
10	Surface	5	3.0349	-0.0115	0.0915	0.4650
12	Average	5	1.9833	-0.0099	0.1045	0.4396
12	Bottom	5	2.0753	-0.0096	0.1412	0.3788
12	Surface	4	1.1315	-0.0069	0.5555	0.0936
15	Average	3	-1.6280	-0.0016	0.8406	0.0158
15	Bottom	3	-1.5487	-0.0016	0.8587	0.0124
15	Surface	3	-1.7017	-0.0016	0.8250	0.0190

5.3.2 Establishment of a Recommended MFL

Establishment of the recommended MFL required developing univariate regressions for the two datasets independently and then, in conjunction with the available biotic data, identifying the resource requiring protection under the MFL. The physical requirements of these resources were then identified with respect to salinity. Based on the ecological considerations discussed above, the 5 ppt surfacewater isohaline was identified as the isohaline which contributed most to the delineation of both the low salinity habitat necessary as nursery areas for nekton and maintenance of the vegetative communities of the Waccasassa. Each of the synoptic salinity datasets (*i.e.,* 1985 and 2005) represented a limited collection of information to associate inflows to salinity in the Waccasassa. However, in each case the 5ppt surface isohaline location was well modeled. Given the small sample size of each of the synoptic salinity surveys, it was beneficial to consider combining the two survey datasets dataset to increase the sample size used for the regression analysis. This approach would permit a more robust estimate of the flow isohaline relationship in the Waccasassa under a broader range of estuarine flow conditions. However, the predicted locations of the isohaline were different due to the fact that the 1985 sampling effort was directed specifically to sampling associated with high tide while the 2005 data collection effort were sampled at random with respect to tide. Therefore, combining the two datasets required adjusting the 2005 data to high tide in order to match the 1985 data and predict the relationship between flow and isohaline location at high tide. Since the 5ppt surfacewater isohaline has been identified as the isohaline which contributed most to the delineation of biota in the Waccasassa, adjusting the 2005 data was performed specifically for the 5ppt surfacewater isohaline. An independent term was added to the univariate regression equation described above to estimate the effect of tidal stage recorded in feet on isohaline location using the equation:

$$\hat{I} = B_0 + B_1 * Discharge + B_2 * Tide$$

Where:

- $\hat{I}$ = Predicted isohaline location
- B_0 = intercept
- B_1 = Coefficient describing rate of change in isohaline location per unit change in discharge
- B_2 = Coefficient describing rate of change in isohaline location per unit change in tidal stage measured in feet

This multi-variable regression equation predicted a 2.363 Km increase in the location of the 5ppt surfacewater isohaline for each 1 foot change in tide (Appendix E-3).

Figure 5-5 shows the combined 5 ppt surface isohaline positions plotted against flow at Gulf Hammock using the unadjusted 2005 data. Figure 5-6 shows the magnitude of each correction in the 2005 data as the difference between the triangle and the star. Finally, Figure 5-7 displays the corrected 2005 data plotted along with the 1985 data. The isohaline locations collected at the higher flows in 2005 (i.e. flows between 450-600cfs) were collected farther in time from high tide and therefore were adjusted more than isohaline locations taken at lower flows. This adjustment had the effect of changing the slope of the relationship between flow and isohaline location for the adjusted data.

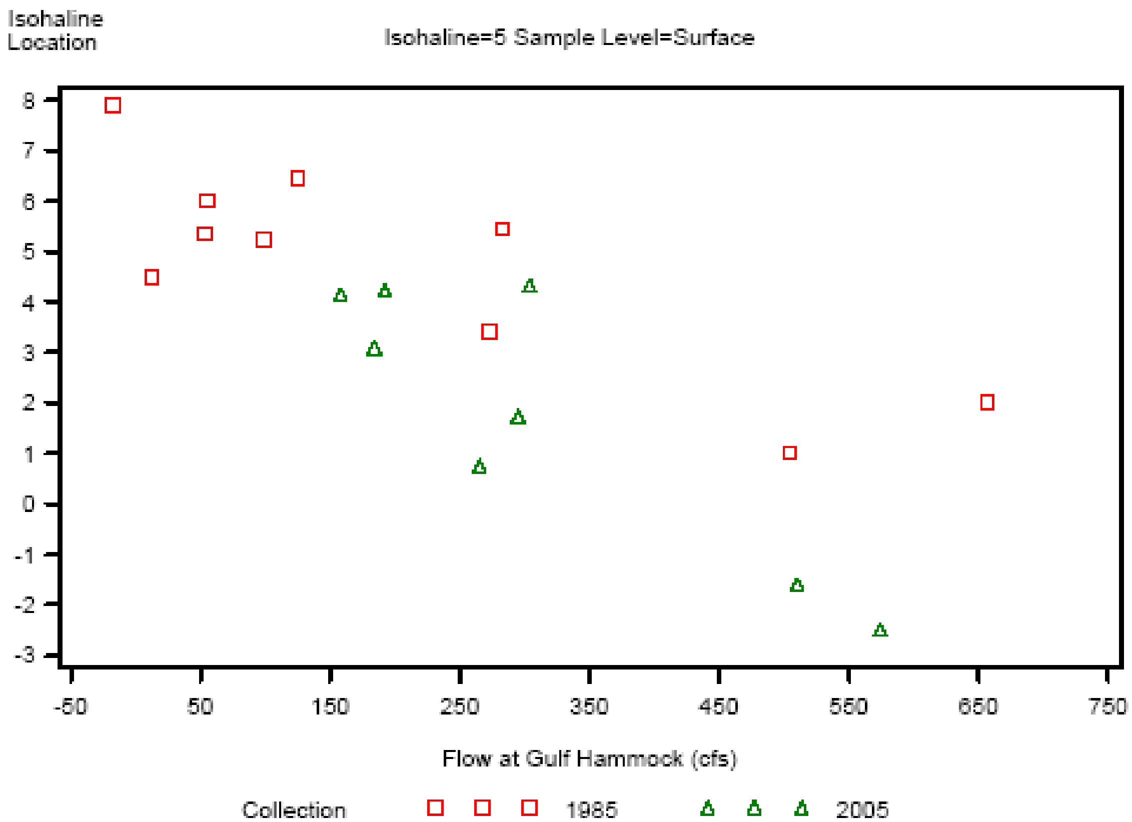


Figure 5-5 Plot of combined 1985 and 2005 isohaline positions in the Waccasassa.

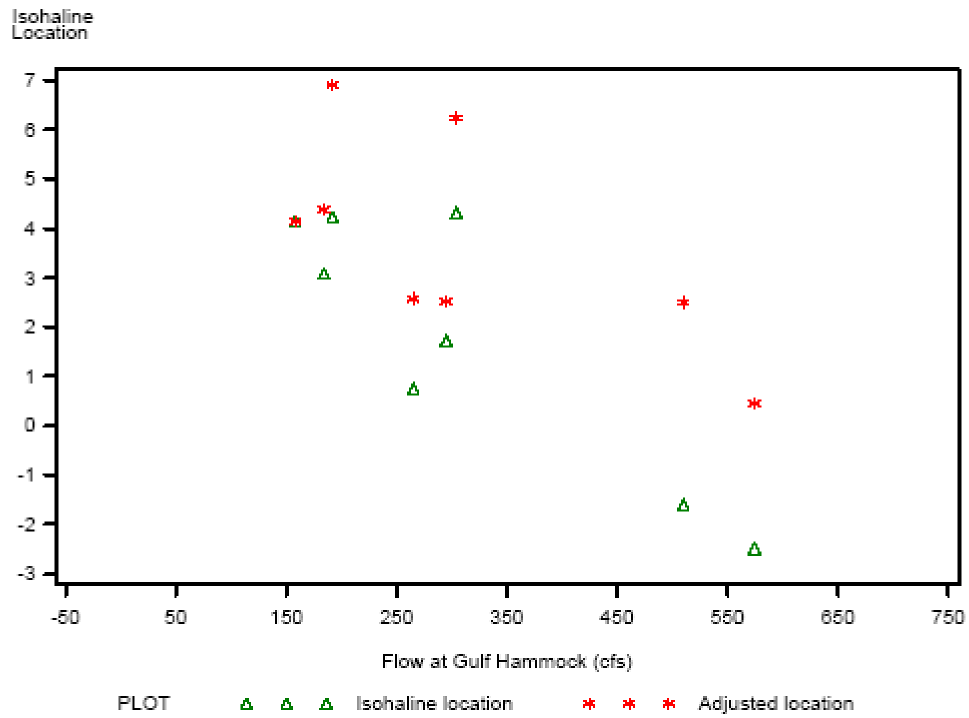


Figure 5-6 Unadjusted 2005 isohaline location and star indicating the adjusted position.

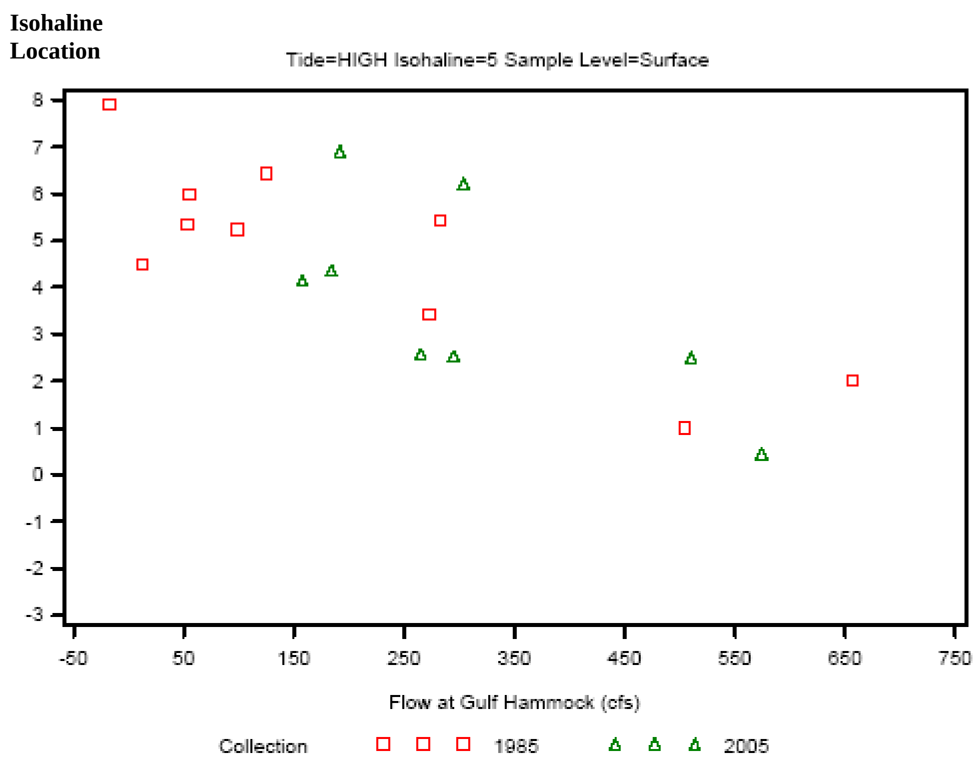


Figure 5-7 Combined 1985 and adjusted 2005 isohaline position in the Waccasassa.

Once the 2005 data were adjusted to high tide, a univariate regression using the stepwise selection approach described in the analytical methods section was used to asses the relationship between the Waccasassa flows from USGS 02313700 and the location of the 5 ppt surface isohaline using the combined dataset. Results suggest that the two-day average flow (i.e., the sample date and the preceding date averaged) produced the most reliable estimate of the isohaline location based on the highest coefficient of determination (Appendix E-4). To establish the recommended MFL, the flow corresponding to the location of the downstream limit of oligohaline vegetative habitat was predicted (i.e., rkm 5.6). This predictive regression relationship suggests that a two-day average flow at USGS02313700 of 98cfs would maintain the 5 ppt surface isohaline at rkm 5.6 at high tide (Figure 5-8). This location would also protect the habitat historically available to recruiting estuarine dependent fishes and benthic invertebrates.

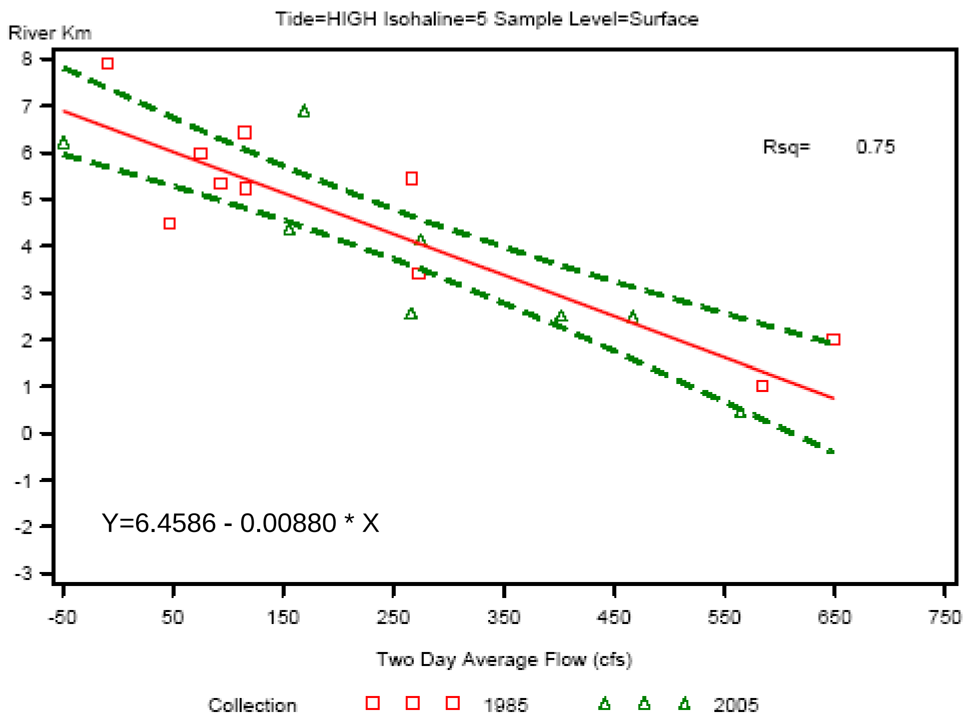


Figure 5-8 Predicted relationship between salinity and the two-day average flow at USGS 02313700 (Bronson) using the 1985 and tide corrected 2005 data combined. Dashed lines are the 95 percent confidence limits.

5.3.3 Estimating Risk

The long-term flow record at USGS 02313700 (1963-2005) indicates that a flow equal to or less than 98 cfs occurs 31.4% of the time (Baseline occurrence). Therefore, risk was defined as an increase in the frequency of occurrence of the 5 ppt surfacewater isohaline above RKM 5.6 due to flow reductions. If this is called the “Relative Risk” (RR = Proportion under MFL conditions /

Proportion under Baseline conditions), then the “Relative Risk Increase” (RRI) due to flow reductions can be calculated as:

RRI = (RR - 1)*100.

Various acceptable levels of risk have been defined in the literature, based upon similar MFL work taking place throughout Florida. Shaw and colleagues’ peer review panel found the 15% loss benchmark established for the Middle Peace River MFL evaluation to be “reasonable and prudent” (Shaw et al., 2005). The 15% benchmark was also supported by the Upper Myakka River MFL peer review panel (SWFWMD Peer Review Panel, 2005). Other values, ranging between 10-33% have also been reported in the literature as acceptable levels of habitat loss. The choice of an appropriate level of acceptable loss or change needs to be based upon various ecological and physical factors, place within the larger context of the status of the system at hand.

For establishment of an MFL, a RRI of 15% was considered to constitute significant risk to the ecological balance in the Waccasassa River system by increasing the frequency of incursions of a 5 ppt surface isohaline above rkm 5.6 from its long-term baseline frequency of 31.4% to 36.1%. The discharge value for the two-day average flow at 02313700 corresponding to a 36.1% frequency of occurrence was 112 cfs. Therefore, the entire flow duration curve for USGS 02313700 was multiplied by the constant: 98 cfs/112 cfs = 0.875 to achieve the flow duration curve under the proposed MFL (Figure 5-9).

The recommended MFL is based on shifting the FDC from its historic baseline to a curve which represents a 15% RRI in the Waccasassa River. The Baseline FDC consists of the FDC established from the period of record data. The MFL FDC is the Baseline FDC shifted by the proposed factor of 0.875 (Figure 5-10). The median Baseline FDC flow shifts from 157 cfs to 137 cfs or a 20 cfs reduction in the median. However, since the MFL is a fixed proportion of flow, the magnitude difference in flow and the RRI values for a given month are relative to the median discharge of that month (Table 5-5). This allows for the MFL to be more protective during times when there is typically less discharge in the Waccasassa River System. For instance, in a typical January the monthly median flow is 200 cfs with about 21.7% of the days below 98 cfs. Under the proposed MFL FDC, the proportion of days with a two-day average flow below 98 cfs would increase to 24.4%, a RRI of 12.4%.

The RRI assessed on a monthly basis varied between 11% and 19.4 % depending on month with November, December, February and March being the most sensitive months to changes in flow under the proposed MFL. It is important that the periods of high flow and floodplain inundation be maintained. The seasonal variability depicted in Figure 5-10 demonstrates that this proposed MFL FDC will preserve the seasonal flow. Figure 5-10 expresses the difference in discharge under baseline and MFL FDCs.

Table 5-5 Monthly median two-day average flows and proportion of discharges below 98 cfs under baseline and MFL conditions. The Relative Risk Increase equates to the percent increase from baseline in the number of days with a two-day average flow less than 98 cfs. The monthly RRI ranged from 11% to 19.4%

Month	Median Discharge	Baseline Proportion	MFL Proportion	Relative Risk Increase
January	200	0.217	0.244	12.4
February	225	0.187	0.220	17.6
March	232	0.175	0.209	19.4
April	131	0.390	0.439	12.6
May	84	0.562	0.624	11.0
June	96	0.506	0.574	13.4
July	155	0.302	0.350	15.9
August	274	0.172	0.196	14.0
September	224	0.212	0.247	16.5
October	123	0.376	0.438	16.5
November	129	0.364	0.432	18.7
December	149	0.288	0.341	18.4

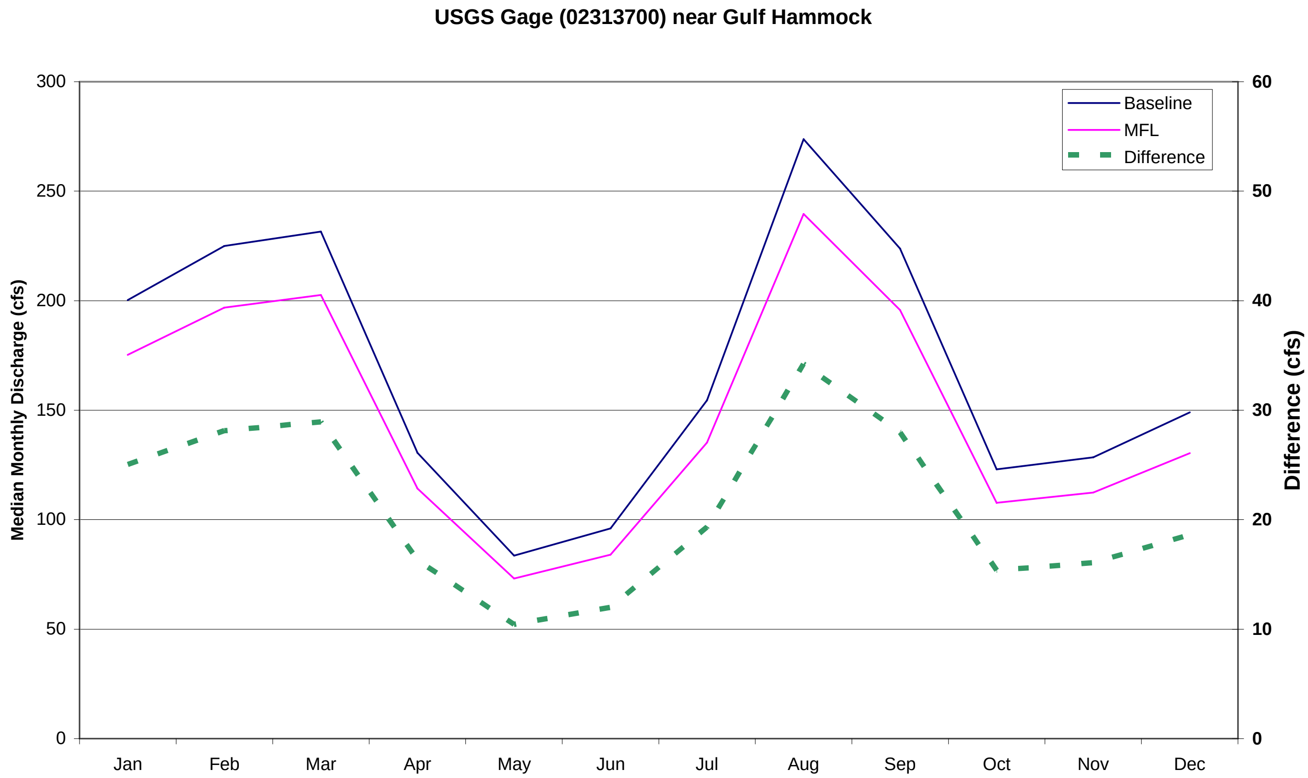


Figure 5-9 Monthly median two-day average discharge at USGS 02313700 for baseline and proposed MFL conditions with the difference plotted as a broken green line.

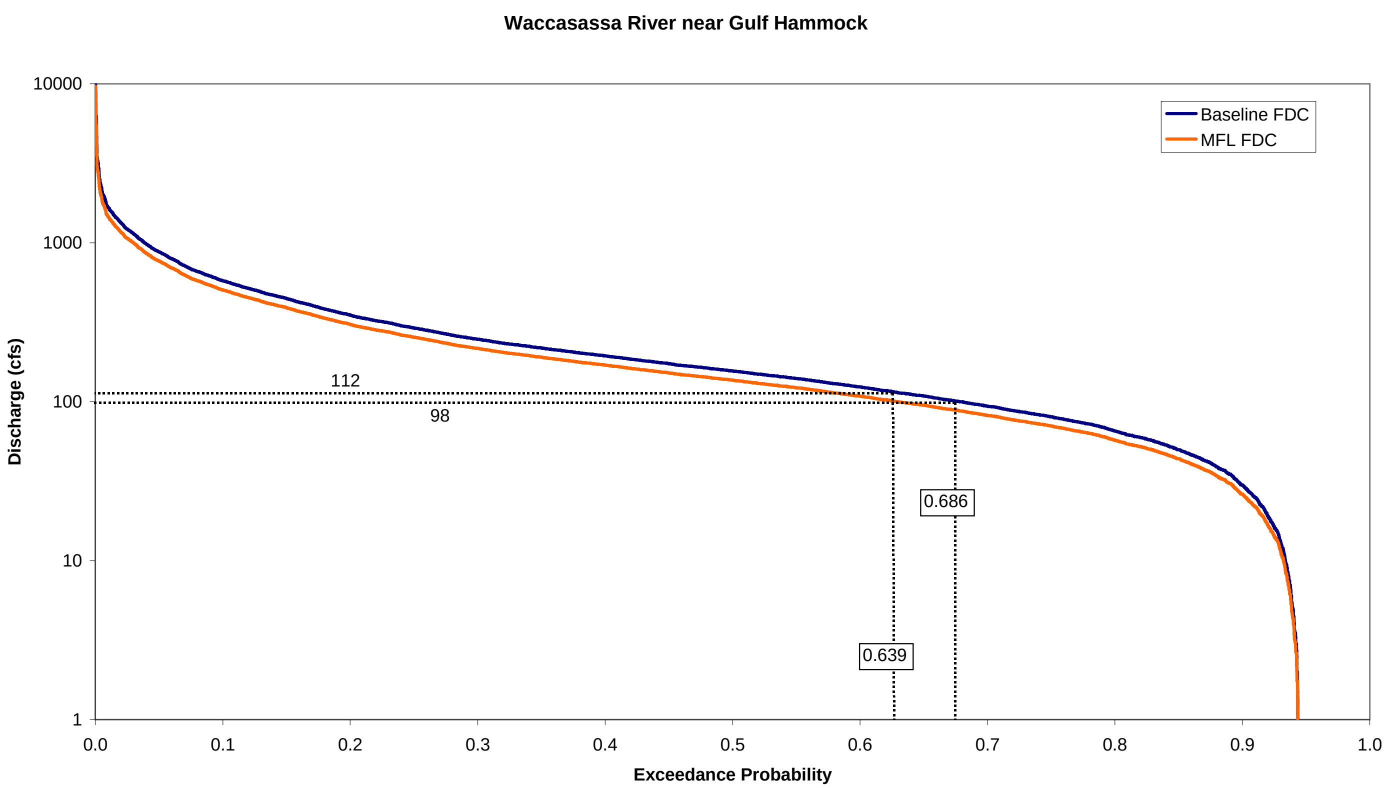


Figure 5-10 Flow duration curve using the two-day average flow at USGS 02313700 for baseline and proposed MFL conditions.

5.3.4 Uncertainties

The Waccasassa is a dynamic system with a large degree of variability with respect to salinity at any particular location within the estuarine portion of the river. There are clearly times when the tidal head moves upstream of the most upstream salinity sampling station in the river as well as times when the entire river is essentially fresh-water. Salinity in the system responds to fresh-water inflows into the system, the passage of cold fronts through the area, prevailing wind direction, tidal amplitudes, and the passage of hurricanes in the Gulf of Mexico (Section 3).

The regression relationships presented above represent best estimates of the functional relationship for isohaline position as a function of discharge at USGS gage 02313700 under normal conditions. While the regression data were sufficient to predict isohaline location as a function of discharge, there is a degree of uncertainty associated with prediction of the specific isohaline location. For example, using the combined data regressions, the best estimate of the location of the 5 ppt surface isohaline at high tide with a two-day average flow of 98 cfs was RKM 5.6. However, the confidence intervals around this estimate suggest that the true mean location of the 5 ppt surface isohaline at a discharge of 98 cfs was between RKM 5.0 and 6.2 (within a 95% confidence interval). The main source of uncertainty is a result of the limited sample size available to derive the predictions of isohaline location. Additional sources of uncertainty come from natural variability associated with the effects of wind direction and variations in tidal amplitude associated with moon phase as well as the sporadic passage of cold fronts and hurricanes in the Gulf of Mexico, all of which express the natural variability in the system and thereby increase the uncertainty of the estimate.

Despite these uncertainties, the models appear to provide a reasonable estimate of the true location of the 5 ppt surface isohaline based on the empirical data from which the models were derived and are supported by qualitative vegetative data taken in association with the salinity monitoring as well as vegetative mapping. The utilization of data collected at high tide allows us to predict the maximum expected salinity that shoreline-associated vegetation would encounter under normal conditions for a given discharge. Therefore, the majority of the time the shoreline vegetation would experience somewhat lower salinities.

Unfortunately, no continuous salinity-recorder data were available to estimate the intra-daily variation of salinities at a particular location. The effects of tide could only be estimated from the data collected in 2005. This estimate was used to correct the 2005 data in order to combine the two data sources and increase the validity and reliability of the predicted isohaline location. Increasing sample size appeared to increase confidence around the predicted isohaline location by reducing the confidence interval around the mean and increasing the reliability of the estimate of the isohaline location.

It should be noted that while an MFL may protect against localized anthropogenic influences that may significantly harm the resource through fresh-water reductions, broad scale environmental changes, such as sea-level rise, may have a profound effect on the estuarine characteristics of the Waccasassa over time with the potential for increased salinity intrusion resulting from increased coastal water surface elevations. Additional monitoring efforts are recommended to substantiate the predicted relationships between discharge at USGS 02313700 and isohaline position, particularly around rkm 5.6, the estimated location of transition from salt marsh to oligohaline habitat. The statistical tools presented here represent best efforts to quantify the effects of discharge at USGS gage 02313700 on salinity in the estuarine portions of the Waccasassa using the best available data and aid in the establishment of an MFL that will minimize the potential for significant harm due to reductions in fresh-water inflows.

5.4 Recommended Levy (Bronson) Blue Spring MFL

As noted in Section 3.3.1 of this report, Levy Blue Spring is located near the headwaters of the Waccasassa River. While the third-magnitude spring is small (median discharge is estimated to be 6.9 cfs), it is an important source of water for the upper Waccasassa River, including the Devil's Hammock area. In addition, the spring is located within a Levy County Park near the town of Bronson. For these reasons, it is necessary to establish a MFL for the spring.

The spring was evaluated relative to the 10 environmental values (Section 1.1) as specified in Chapter 62-40.473, F.A.C. and it was determined that two values could be the most restrictive for MFL development. These are recreation in and on the water and maintenance of fresh-water storage and supply. Specifically, the large spring pool and low discharge resulted in concern for public health and the location of the spring results in importance for the maintenance of water supply to the river downstream.

Chapter 64E-9 F.A.C. (Swimming Pools and Bathing Places) establishes criteria for public health considerations. As noted in Section 3.3.1, this rule requires that bathing water have a flow through of 500 gallons per bather per 24 hours. With respect to Levy Blue Spring, flow does not appear to limit use of the spring pool for recreational bathing. Based on the flow through requirement, the current capacity is several thousands persons per day. Furthermore, a reduction of flow to 5 cfs, for example, would not significantly limit the number of bathers. Therefore, recreational use was not found to limit water supply.

It is recommended, therefore, that the MFL be developed on the basis of maintaining flow to the upper Waccasassa River. This MFL addresses the maintenance of fresh-water supply criterion, but it also addresses fish and wildlife habitats and the passage of fish and aesthetic and scenic attributes.

As noted in Section 3.3.1, Levy Blue Spring appears to contribute approximately 10 to 25 percent of the discharge of the Waccasassa River at the US 19 gage. At high river flow, this percentage drops to less than 5%. At low river flow, the percentage of flow contributed by the spring approaches, and may exceed, 100%. In the analysis presented in Section 3.3.1, times when flow from the spring appeared to exceed flow in the Waccasassa River at U.S. 19 were attributed to either uncertainty associated with synthesizing spring discharge data or losses through evapotranspiration in the riverine wetlands between the spring and U.S. 19. The latter is likely to be true, and, if so, the spring plays a significant role in hydrating wetlands during droughts.

Based on the importance of the spring as a source of water from the upper river, it is proposed that the MFL be set to conserve discharge from the spring while allowing for some additional use. It is proposed that the MFL FDC be limited to 90% of the Baseline FDC. This would result in reducing the median discharge from the spring from an estimated 6.9 cfs to 6.2 cfs (Table 5-6). This limitation results in a maximum reduction of 0.7 cfs, or 452,000 gallons per day, at median flow.

Figure 5-11 illustrates the proposed Baseline and MFL FDCs for Levy Blue Spring. Table 5-6 presents the percentiles from the two FDCs and the difference between the two – the amount of potentially available water over the range of discharge conditions.

Table 5-6 Comparison of the Baseline FDC for Levy Blue Springs with the proposed MFL FDC.

FDC	Percentiles and Discharge Amounts (cfs)						
	P_5	P_{10}	P_{25}	P_{50} - Median	P_{75}	P_{90}	P_{95}
Baseline	2.40	1.30	4.35	6.9	11.2	15.6	17.3
MFL	2.16	1.17	3.91	6.2	10.1	14.1	15.6
Difference	0.24	0.13	0.44	0.7	1.1	1.5	1.7

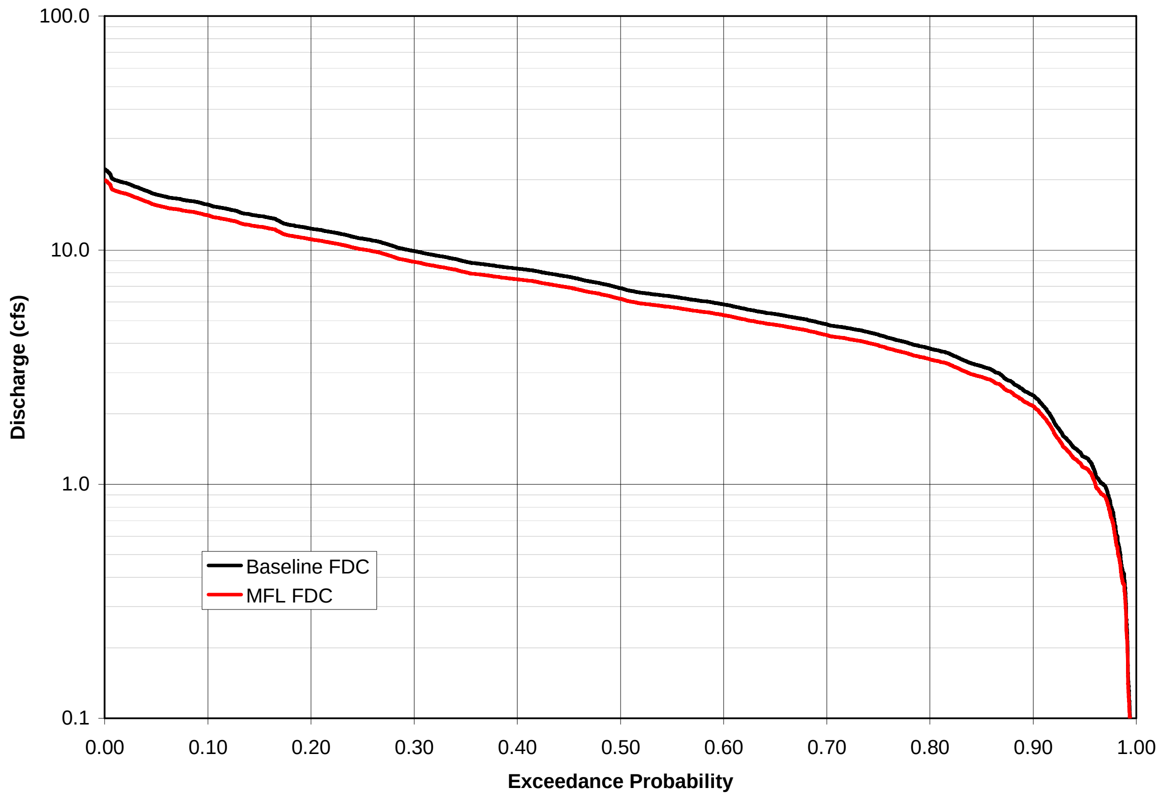


Figure 5-11 Suggested allowable shift in the flow duration curve for Levy Blue Springs.

TAB 6

6.0 Summary and MFL Recommendations

6.1 Summary

The Waccasassa River is a very scenic and relatively undisturbed river basin within Florida. The river basin is characterized by a variety of swamps and pine flatwoods from Gilchrist County down to the tidal reaches of Levy County, before emptying into Waccasassa Bay. The River encompasses two major spring systems, the Wekiva and Levy Blue Springs, second and third magnitude springs, respectively. Levy Blue Spring is on the District's priority water body list and the Wekiva is not listed because of its location on private property.

The Waccasassa River is recognized as a high quality river system as noted by its designation as an Outstanding Florida Water. The estuary system also includes a valuable state resource in the Waccasassa Bay Preserve State Park encompassing 34,000 acres and ranked as the sixth largest state park in Florida.

6.1.1 Waccasassa River Study Area

The Waccasassa River study area is defined as those portions of the Waccasassa hydrologic unit that constitute the surface water drainage basin of the Waccasassa River and its tributaries, including Cow Creek, Tenmile Creek, Wekiva River, and McGee Branch. The extent of the area contributing direct run-off to the Waccasassa River is approximately 400 square miles (Figure 1-1).

The River begins along the southern margin of the Waccasassa Flats. A small portion of the surface flow from the Flats actually contributes to the flow of the river. The 1,600-foot long Levy Blue Spring run discharges into the Little Waccasassa River approximately 1,000 feet upstream from its confluence with the Waccasassa River (Figure 1-1), and this is generally considered the functional headwaters of the river.

Waccasassa Bay is a shallow embayment extending into the Gulf of Mexico between Cedar Key and the Withlacoochee River. The bay receives discharge from the Waccasassa River, as well as Otter Creek and Ten Mile Creek. The bay is an important component of the estuary that supports sport and commercial fisheries, which rely heavily on the ecological functions of the tidally influenced marshes and creeks associated with the river.

6.1.2 Levy Blue Spring

Levy Blue Spring (Bronson Blue Spring) is located in a Levy County park. The spring discharges into a run that is approximately 40-50 feet in width (Rosenau et al., 1977: Scott et al., 2004) and 1,600 feet in length. Levy Blue Springs is widely considered the headwaters of the Waccasassa River. The spring bowl does not contain substantive aquatic vegetation. However, the spring run does contain abundant aquatic and emergent vegetation and is surrounded by a dense, lowland swamp forest. Discharge measurements from this historic third magnitude spring range from 1.7 cfs to 22.5 cfs with a median discharge of 8.1 cfs.

6.2 MFL Evaluation Procedure

The evaluations performed for the establishment of MFLs for the two priority water bodies (Waccasassa River and Estuary and Levy Blue Spring) were conducted with the following approach:

1. Compile all "best available information" relative to the water bodies;
2. Evaluate information to determine which flow and/or level relationships for each waterbody lead to adverse impacts to the water resource or related ecology;

3. Identify the limiting target criteria that, if protected from a significant adverse impact, will protect all other applicable criteria;
4. Recommend a MFL that will protect the waterbody and related ecology from "significant harm".
5. Consider specific water resource values to ensure applicable values are sufficiently protected from significant harm.

6.3 MFL Resource Value Summary

The most limiting water resource values (Chapter 62-40.473, F.A.C) to be protected from a significant adverse impact were concluded to be the following:

Waccasassa River -

Estuarine Resources, including Benthic invertebrates, Nekton, and Vegetative communities

Levy Blue Spring –

Maintenance of Freshwater Storage and Supply, particularly low flow contribution to the Waccasassa River.

6.3.1 MFL Water Resource Value Considerations

In the following sections the Baseline and MFL Flow Duration Curves (FDCs) are presented. As discussed in Sections 3.2.1 and 5.1.6, the Baseline FDC is developed using the period of record data (measured and synthesized) and represents conditions upon which the MFL was established. Unless the historic data upon which the MFLs were based change, the Baseline FDC remains unchanged as permitting proceeds. The MFL FDC is developed to represent the MFL, or significant harm levels, for the water body.

Waccasassa River

1. The 5 ppt surface water isohaline was identified as the isohaline that contributed most to the delineation of both the low salinity habitat necessary as nursery areas for nekton, habitat for benthic invertebrates, and maintenance of the vegetative communities of the Waccasassa River.
2. The 5 ppt surface water isohaline would be maintained below RKM 5.6 by a two-day median flow of 98 cfs as measured at the USGS flow gage near Gulf Hammock (USGS Gage 02313700).
3. A 15% "Relative Risk Increase" (RRI, see Section 5) to the estuarine habitat was identified as the maximum change that would prevent significant risk by damaging the ecological balance in the estuary. Reductions in flow that would allow no more than a 15% RRI would shift the frequency of incursions of the 5 ppt surface isohaline from it's baseline frequency of 31.4% to 36.1%.
4. This 15% RRI would result in a shift from 157 cfs median flow on the Baseline Flow Duration Curve to a 137 cfs median flow, or a 20 cfs reduction. Reductions at other flow frequencies would be scaled proportional to flow in order to protect inundation episodes in the floodplain swamps and wetlands of the river system.

Levy Blue Spring

1. Discharge from Levy Blue Spring comprises as little as 5% of the upper Waccasassa River flow at high flow periods and as much as 100% during low flow periods. Additionally, it appears that flows from Levy Blue Spring are significant to the hydration of the wetlands of the upper Waccasassa, including the Devil's Hammock, at low flows.

2. A 10% flow reduction was identified as a maximum to prevent significant reductions in the associated water resources. A 10% reduction of flow from the Baseline Flow Duration Curve would result in a shift of a median flow of 6.9 cfs to 6.2 cfs, or a 0.7 cfs reduction. Reductions at other flow frequencies would be scaled proportional to flow.

6.4 Recommended MFLs

6.4.1 Waccasassa River – Recommended MFL

It is proposed that the MFL Flow Duration Curve for the Waccasassa River be set at 87.5% of the Baseline Flow Duration Curve for the gage on the Waccasassa River near Gulf Hammock (Figure 6-1; Table 6-1).

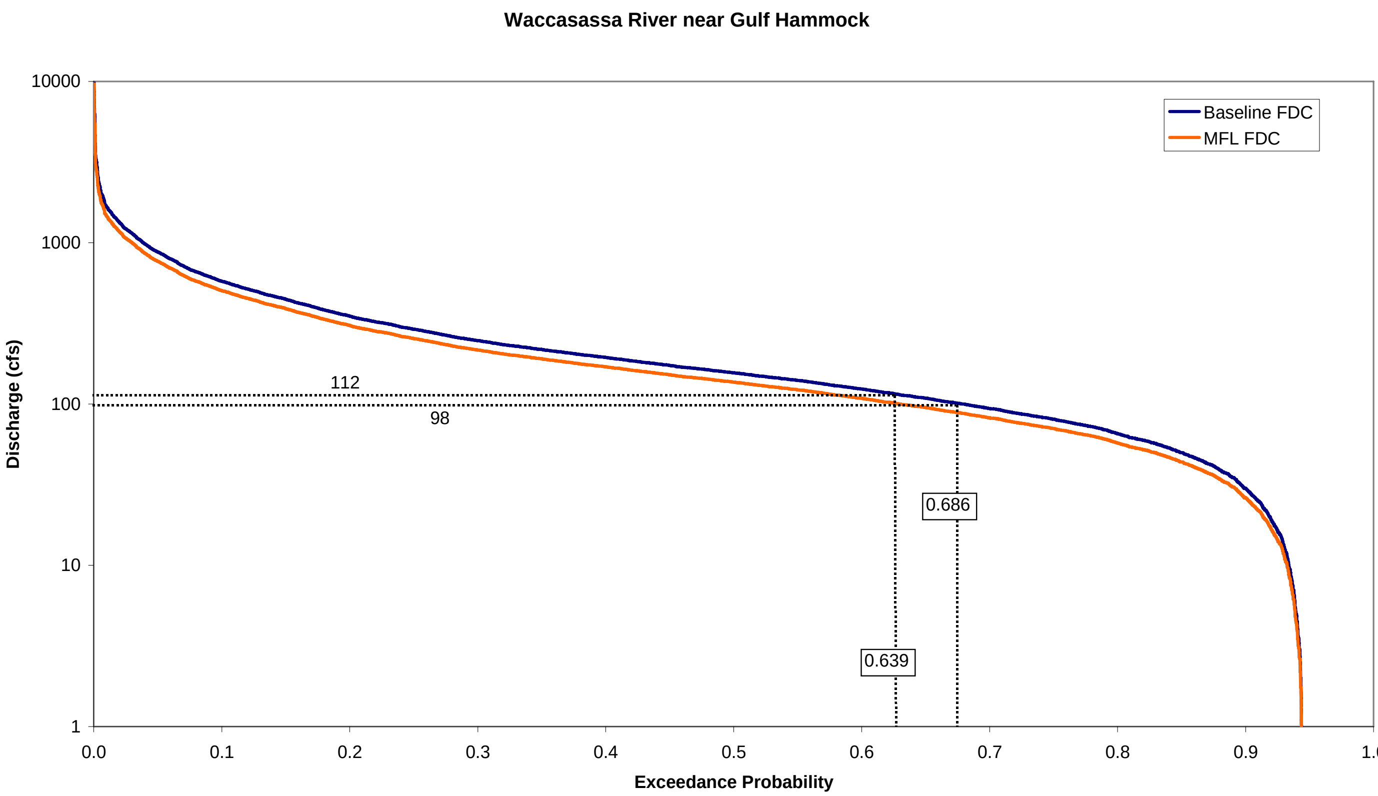


Figure 6-1. Flow duration curve for baseline and proposed MFL of the Waccasassa River

In order to determine if the recommended MFL avoids significant adverse impacts to each of the water resource values found in Chapter 62-40.473 F.A.C., the recommended MFL was evaluated with respect to the ecological and human use values for the Waccasassa River, as discussed in Section 1.1 and summarized in Table 6-2.

Table 6-1. Percentile distributions of the Baseline and proposed MFL flow duration curves for the Waccasassa River near Gulf Hammock gage. The column labeled Difference represents the amount of potentially available water.

Exceedance Percentile	Baseline FDC (cfs)	MFL FDC (cfs)	Difference (cfs)
95	-6	-5	-1
90	30	26	4
80	66	57	8
70	94	82	12
60	124	109	16
50	157	137	20
40	195	170	24
30	248	217	31
20	350	306	44
10	576	504	72
5	875	765	109

Table 6-2. Summary consideration for each water resource value for the Waccasassa River Recommended MFL.

Blue shading indicates applicable water resource value

ECOLOGIC & HUMAN USE VALUE	IS VALUE APPLICABLE TO WATER BODY?	REQUIREMENTS TO AVOID SIGNIFICANT ADVERSE IMPACT	DOES RECOMMENDED MFL ADDRESS VALUE?
Recreation in and on the water	Yes	Maintains fishing and boating opportunities	Yes
Fish and wildlife habitats and the passage of fish	Yes	Fish and wildlife habitats are maintained	Yes
Estuarine resources	Yes	Avoids significant risk to most sensitive benthic and vegetative communities, and nekton	Yes
Transfer of detrital material	No	NA	NA
Maintenance of freshwater storage and supply	Yes	Availability of water for future use	Yes
Aesthetic and scenic attributes	Yes	River continues to flow at acceptable visual levels	Yes
Filtration and absorption of nutrients and other pollutants	No	NA	NA
Sediment loads	No	NA	NA
Water quality	No	NA	NA
Navigation	No	NA	NA

Blue shading indicated applicable water resource values

6.4.2 Levy Blue Spring– Recommended MFL

It is proposed that the MFL flow duration curve for Levy Blue Spring be set at 90% of the Baseline Flow Duration Curve (Figure 6-2; Table 6-3)

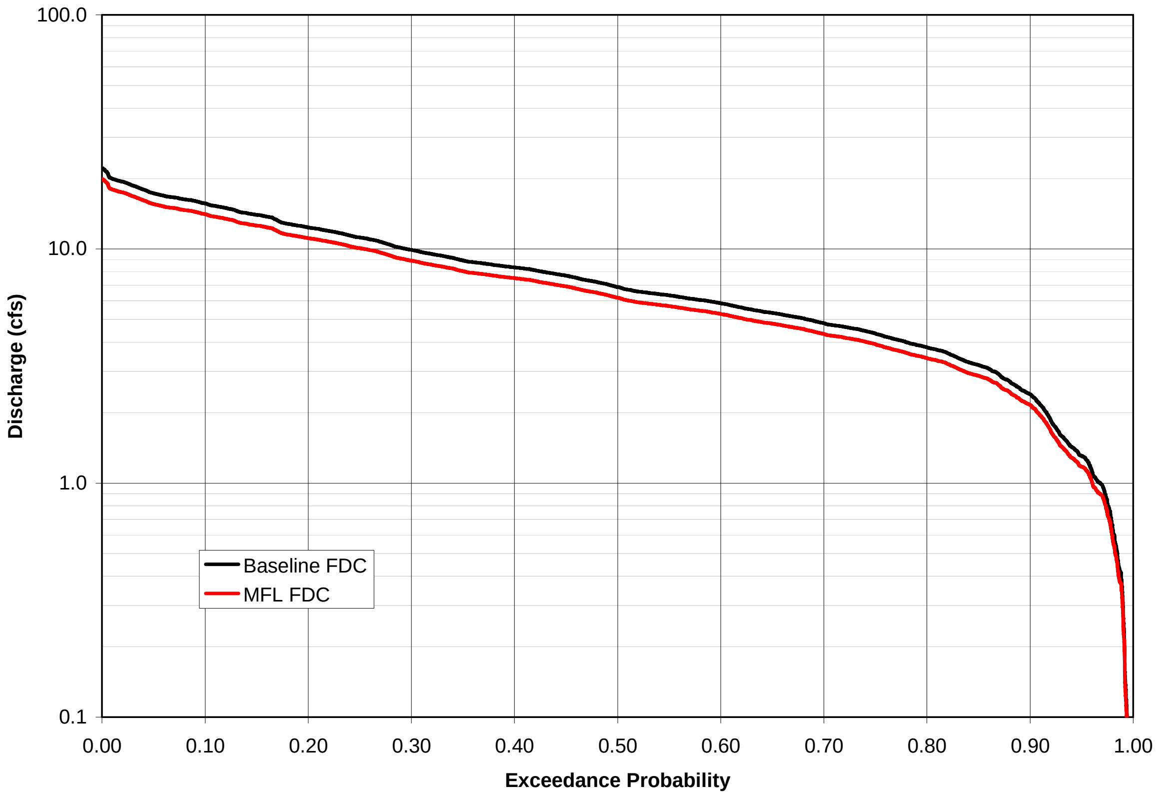


Figure 6-2. Suggested allowable shift in the flow duration curve for Levy Blue Springs.

Table 6-3. Percentile distributions of the Baseline and proposed MFL flow duration curves for Levy Blue Spring. The column labeled Difference represents the amount of potentially available water from the spring.

Exceedance Percentile	Baseline FDC (cfs)	MFL FDC (cfs)	Difference (cfs)
5	2.40	2.16	0.24
10	1.30	1.17	0.13
20	3.8	3.42	0.38
30	4.8	4.33	0.48
40	5.9	5.28	0.59
50	6.87	6.18	0.69
60	8.3	7.50	0.83
70	9.9	8.92	0.99
80	12.4	11.13	1.24
90	15.6	14.07	1.53
95	17.3	15.56	1.74

In order to determine if the recommended MFL avoids significant adverse impacts to each of the water resource values found in Chapter 62-40.473 F.A.C., the recommended MFL was evaluated with respect to the ecological and human use values as discussed in Section 1.1 and summarized in Table 6-4.

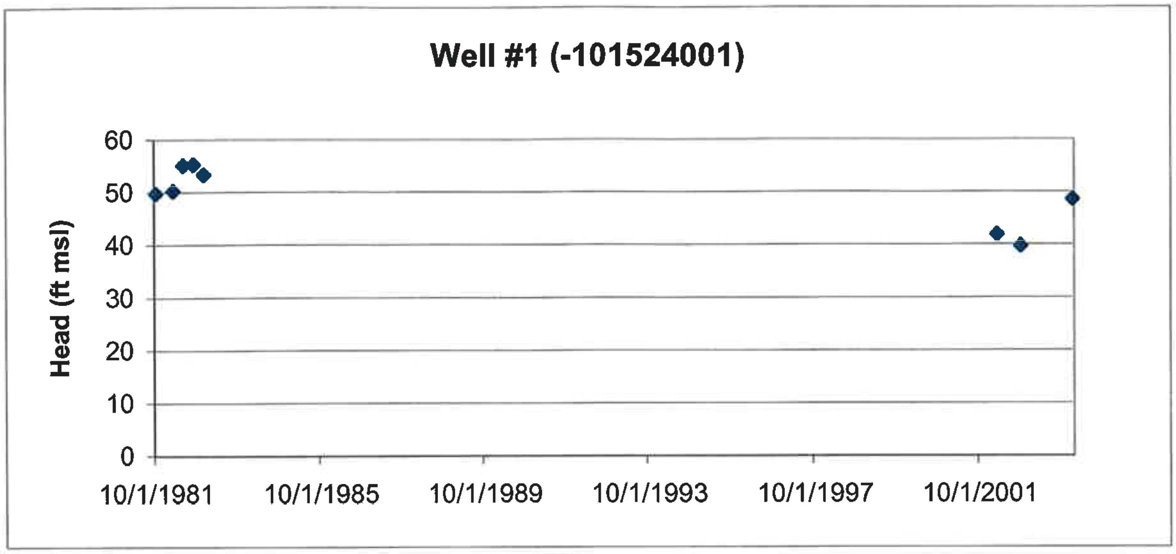
Table 6-4. Summary considerations for each water resource value relative to the Levy Blue Spring recommended MFL.

ECOLOGIC & HUMAN USE VALUE	IS VALUE APPLICABLE TO WATER BODY?	REQUIREMENTS TO AVOID SIGNIFICANT ADVERSE IMPACT	DOES RECOMMENDED MFL ADDRESS VALUE?
Recreation in and on the water	Yes	Allows maintenance of recreational use of spring and spring run	Yes
Fish and wildlife habitats and the passage of fish	No	NA	NA
Estuarine resources	No	NA	NA
Transfer of detrital material	No	NA	NA
Maintenance of freshwater storage and supply	Yes	Maintains sufficient flow at low flow periods	Yes
Aesthetic and scenic attributes	Yes	Maintains flow in spring pool and spring run	Yes
Filtration and absorption of nutrients and other pollutants	No	NA	NA
Sediment loads	No	NA	NA
Water quality	No	NA	NA
Navigation	No	NA	NA

Blue shading indicates applicable water resource value

It is further recommended that the data used for Levy Spring and further data collected in the future be reviewed to further calibrate the recommended MFL Flow duration curve.

APPENDIX A



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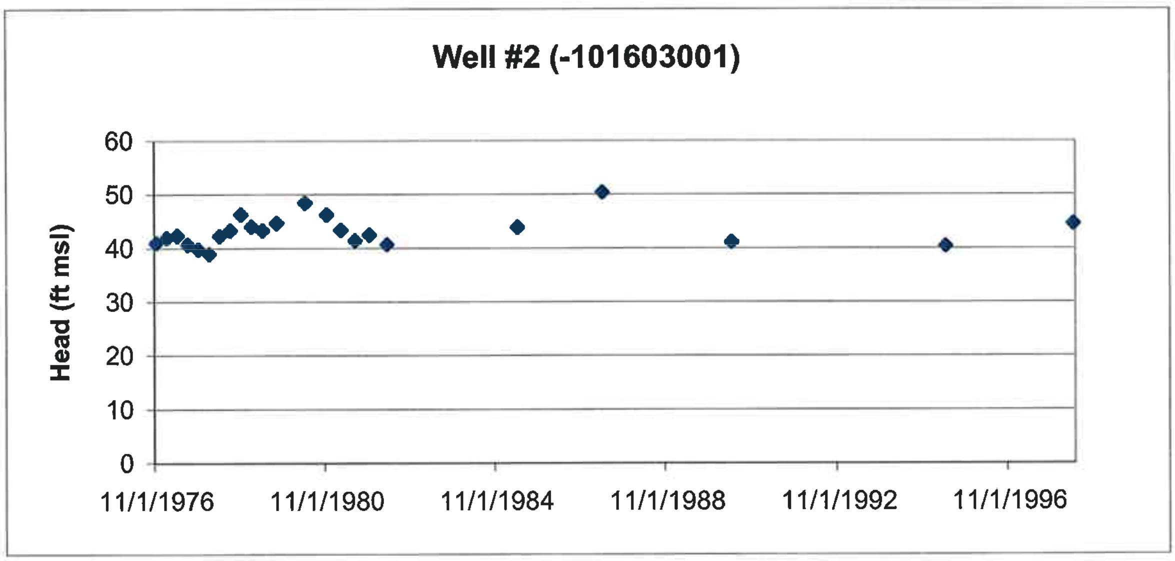

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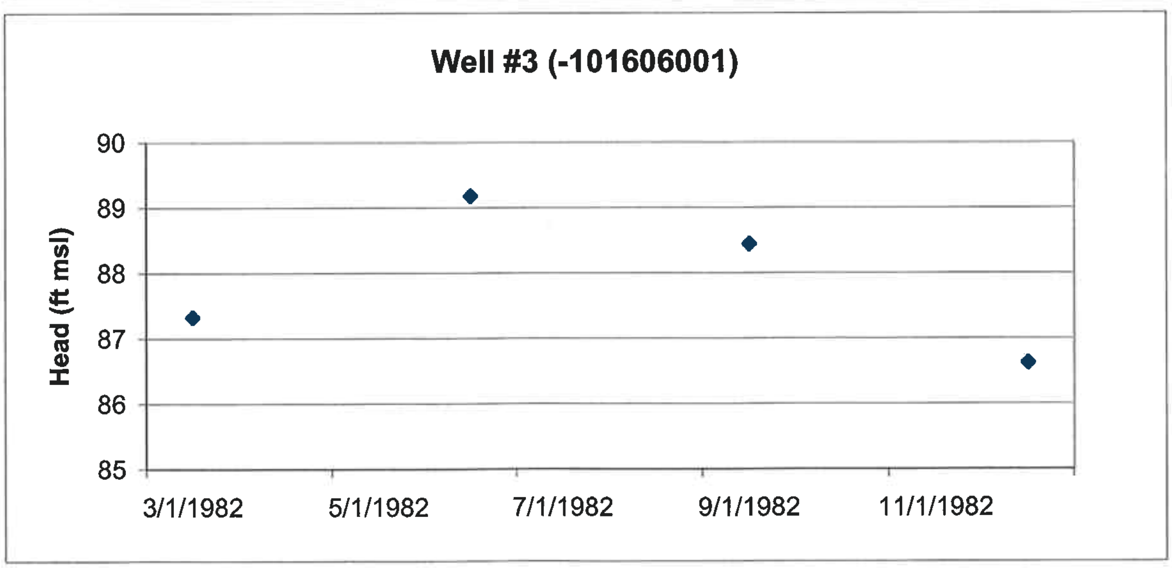

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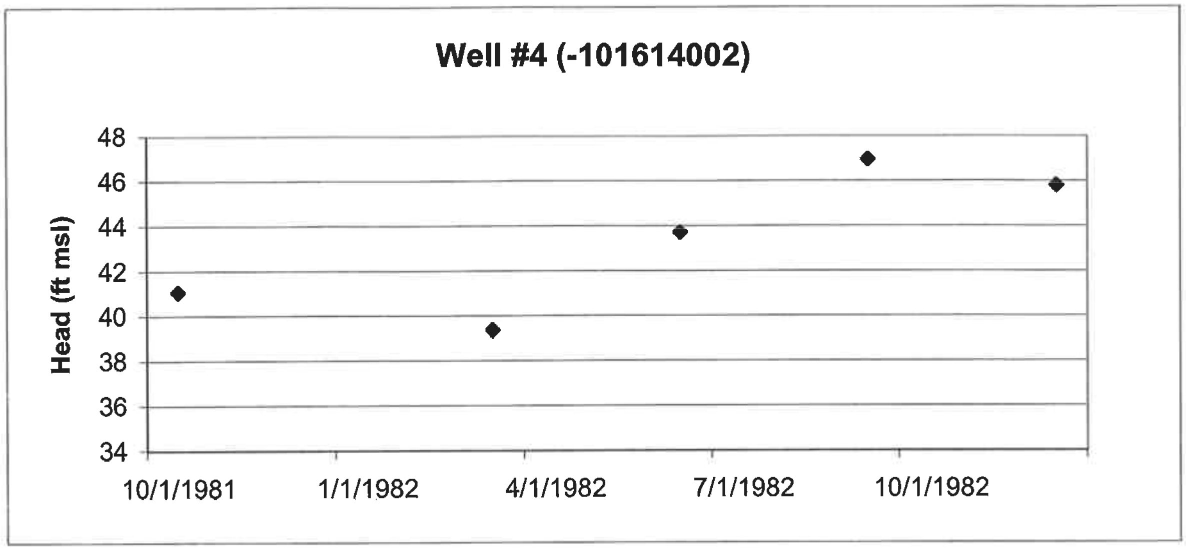
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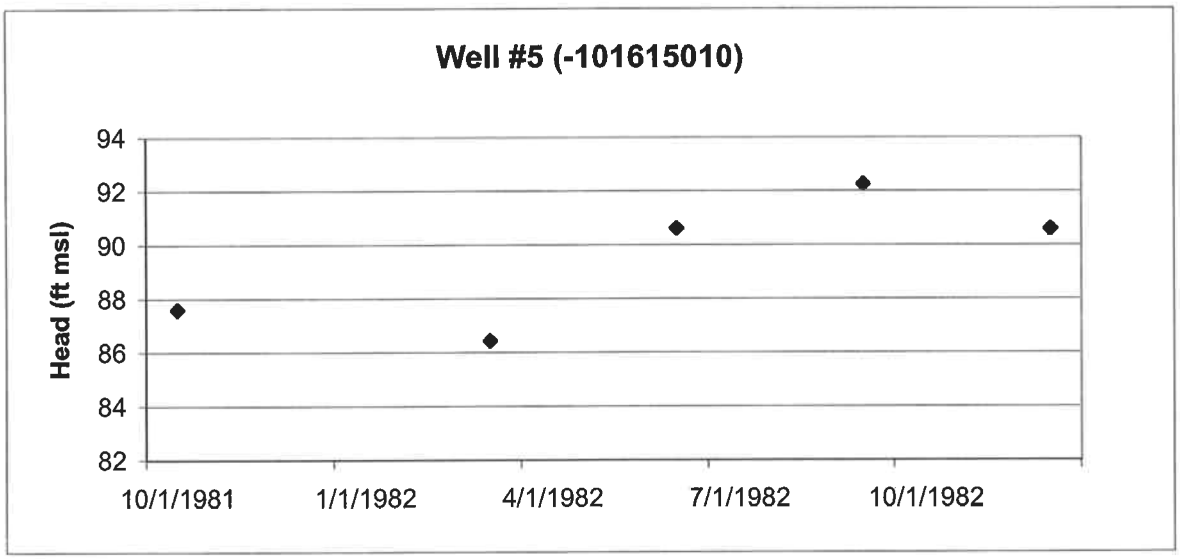
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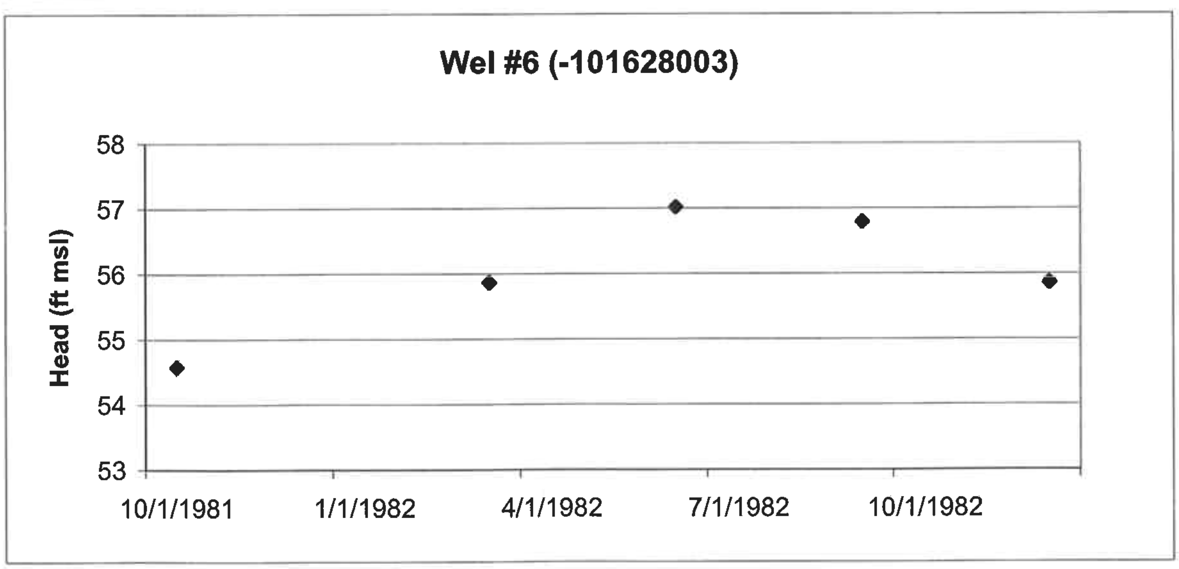
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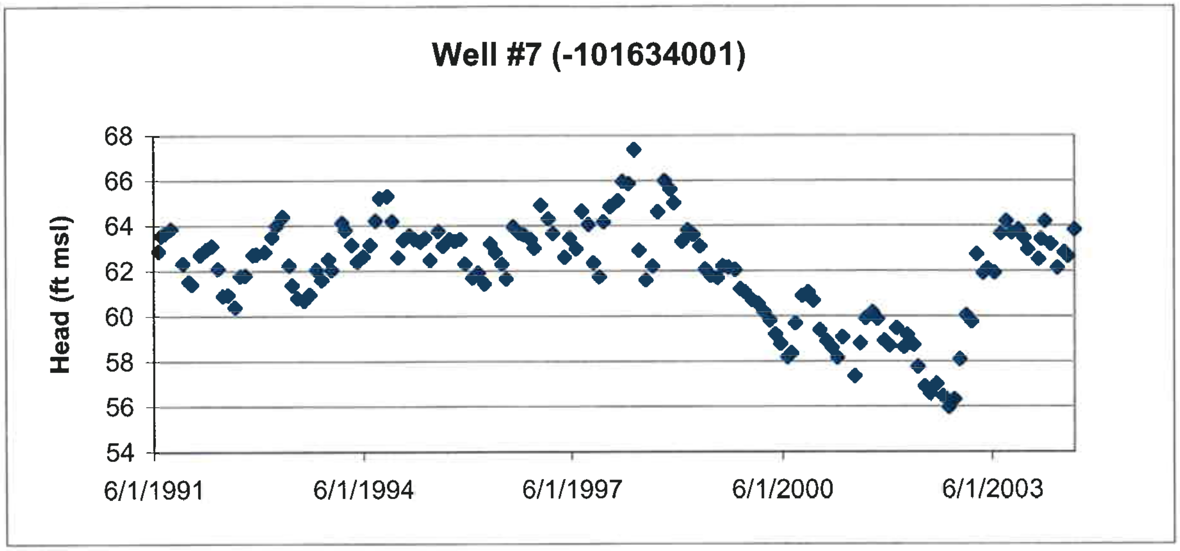
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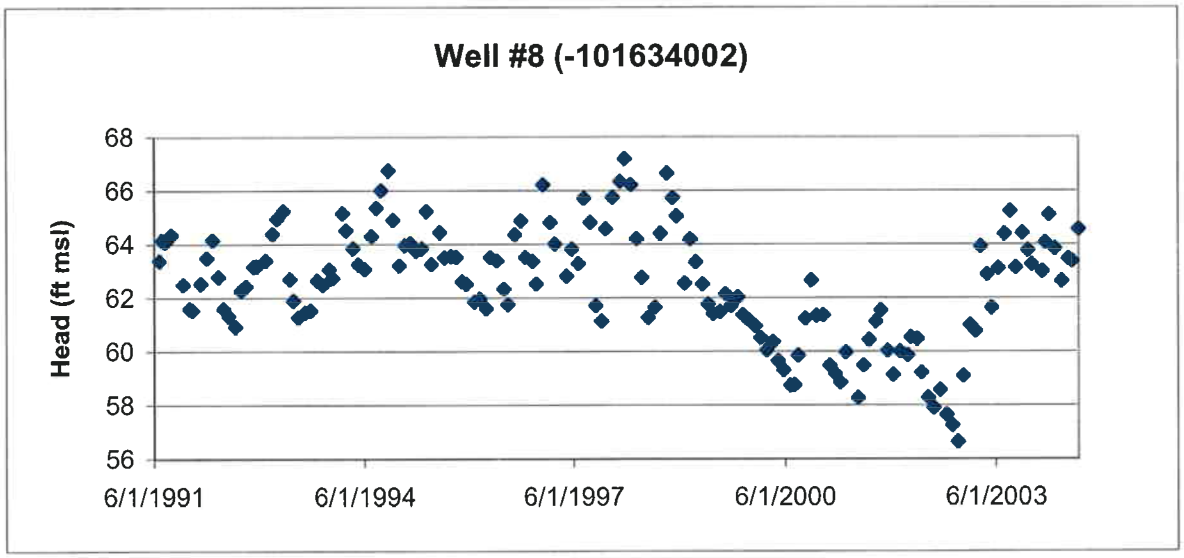
6/1/2003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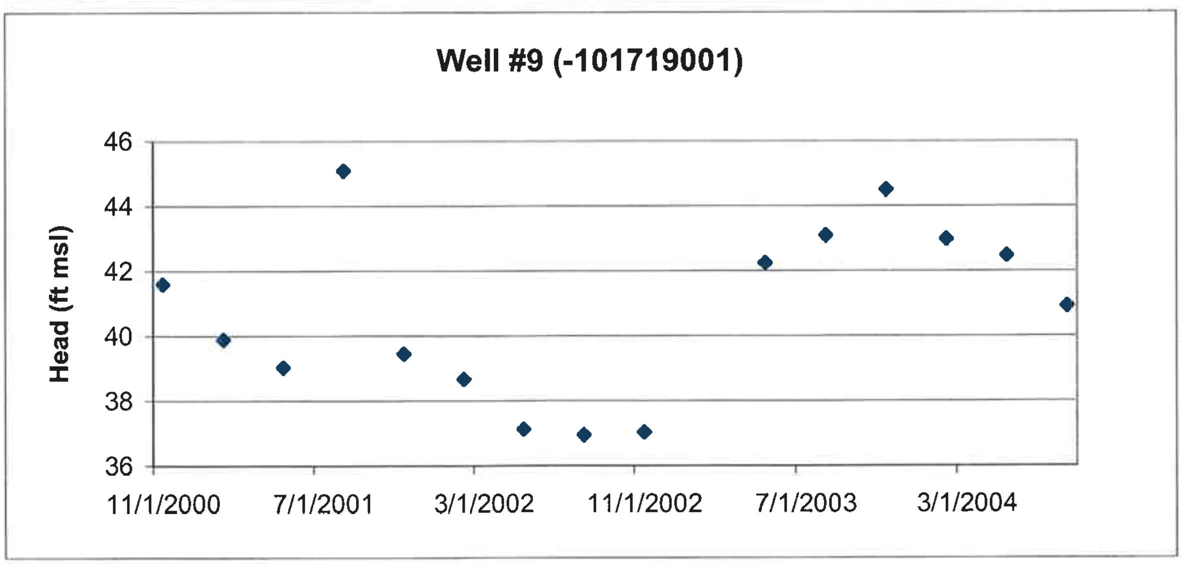
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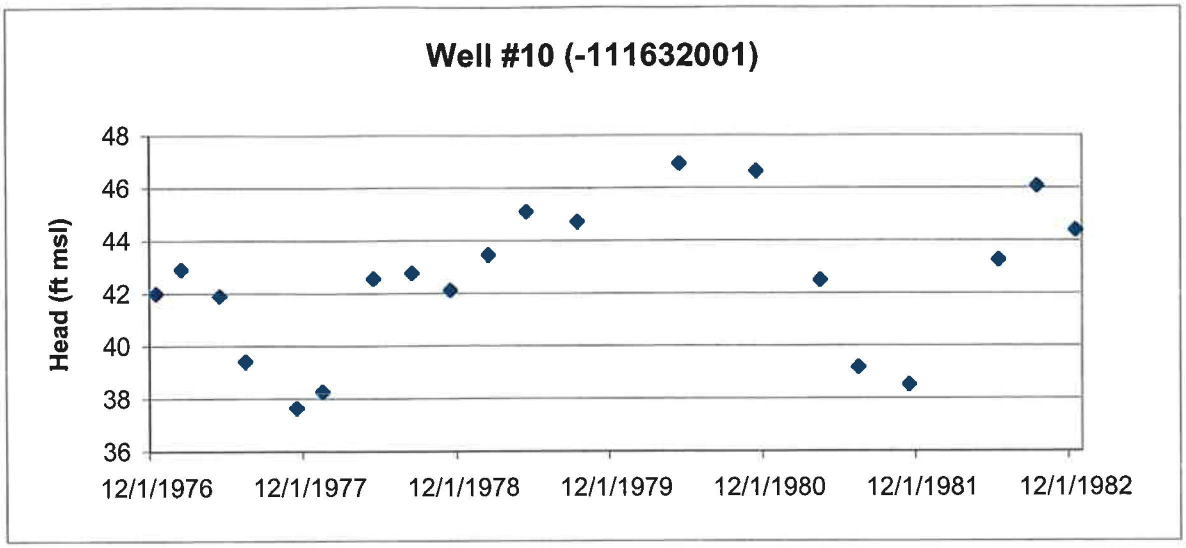
3/1/2004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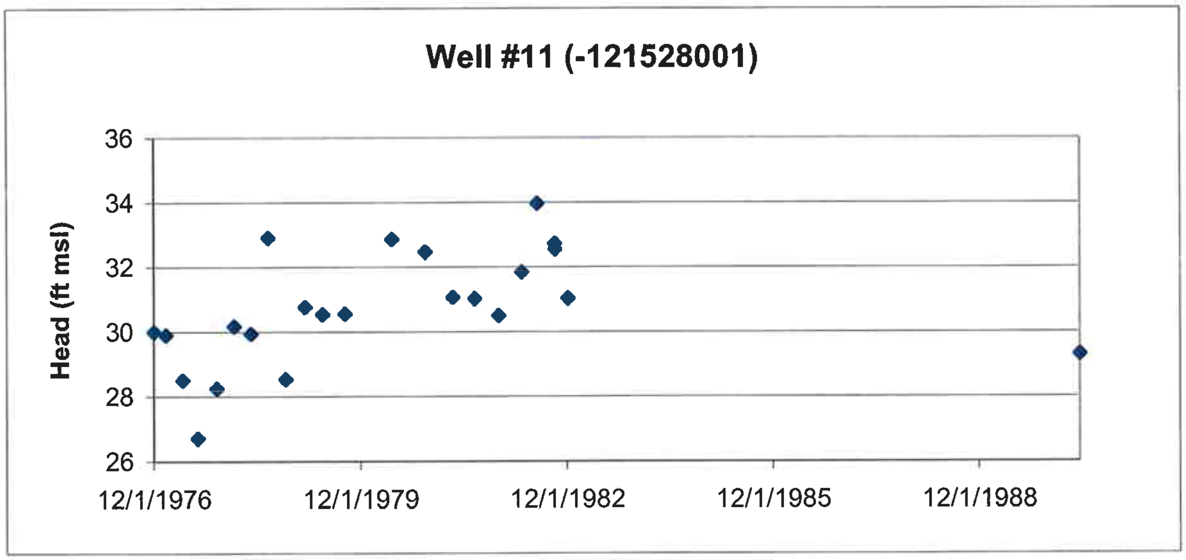
12/1/1981
12/1/1982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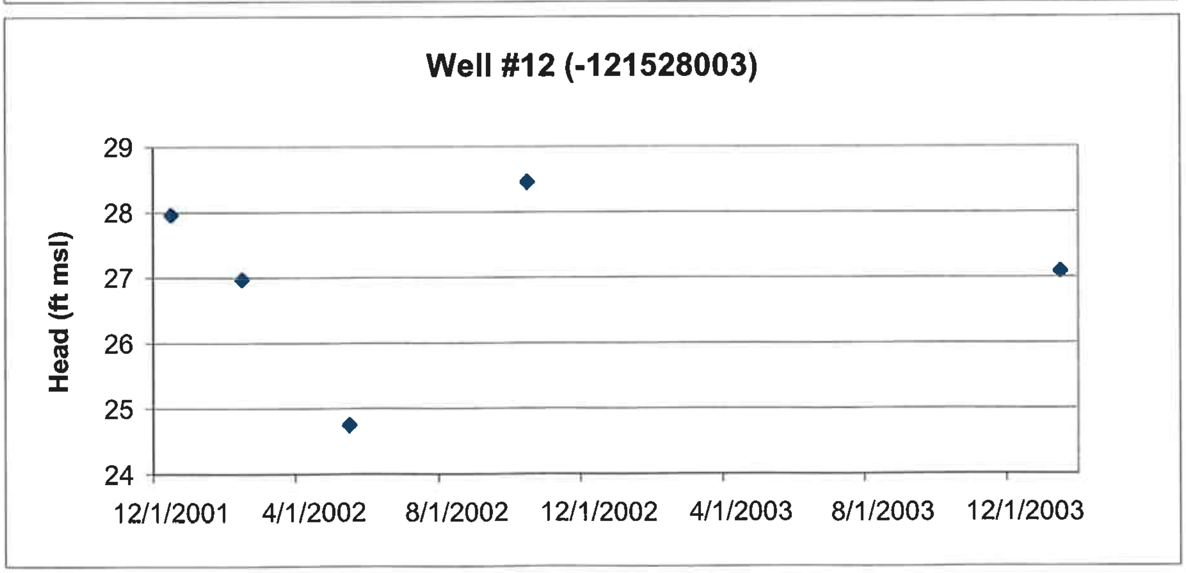
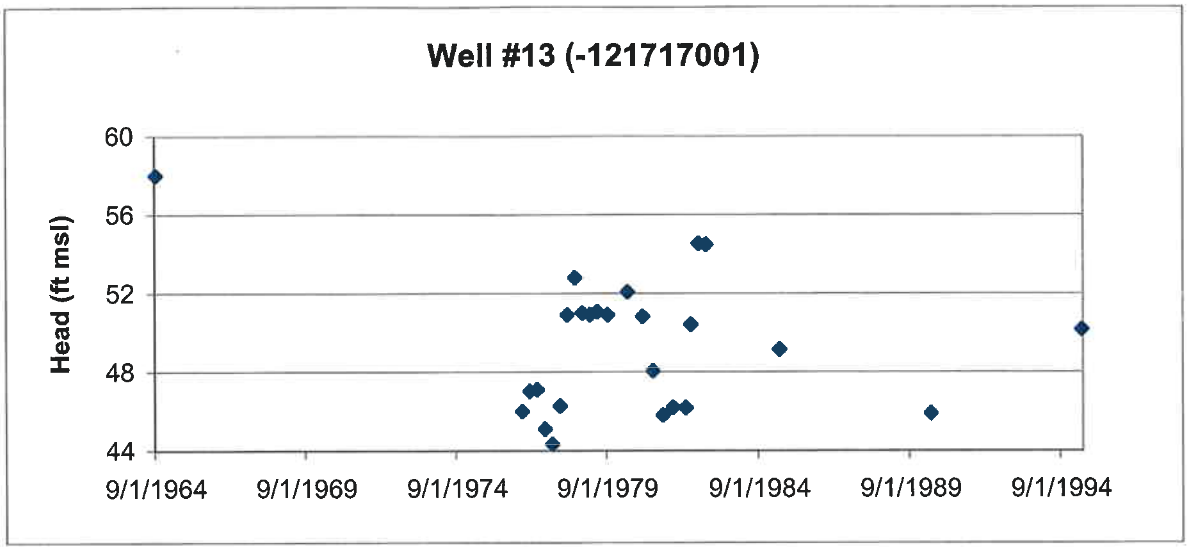
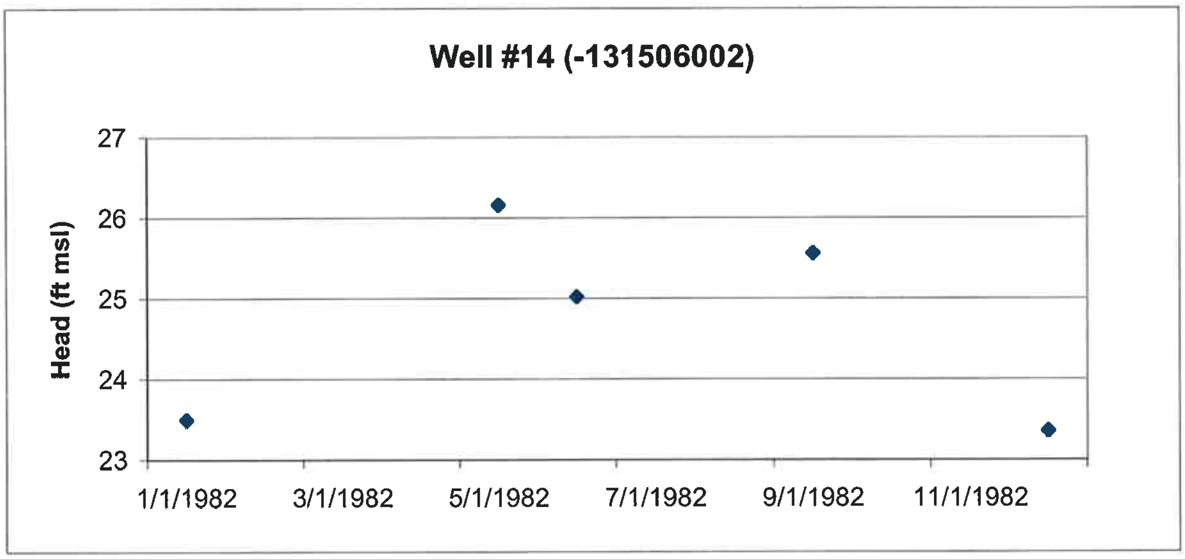
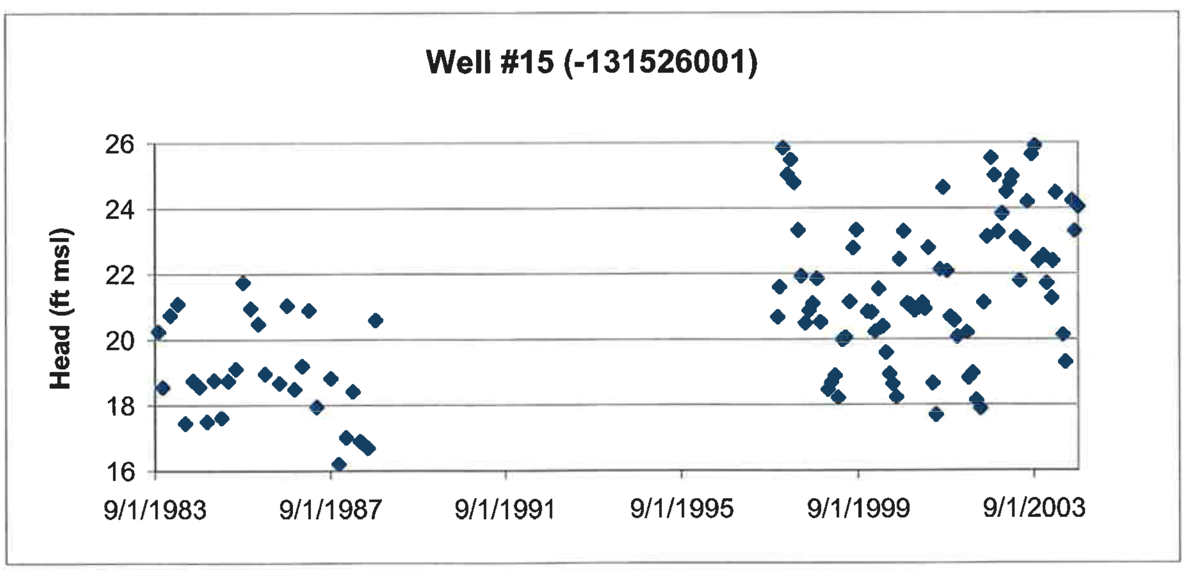
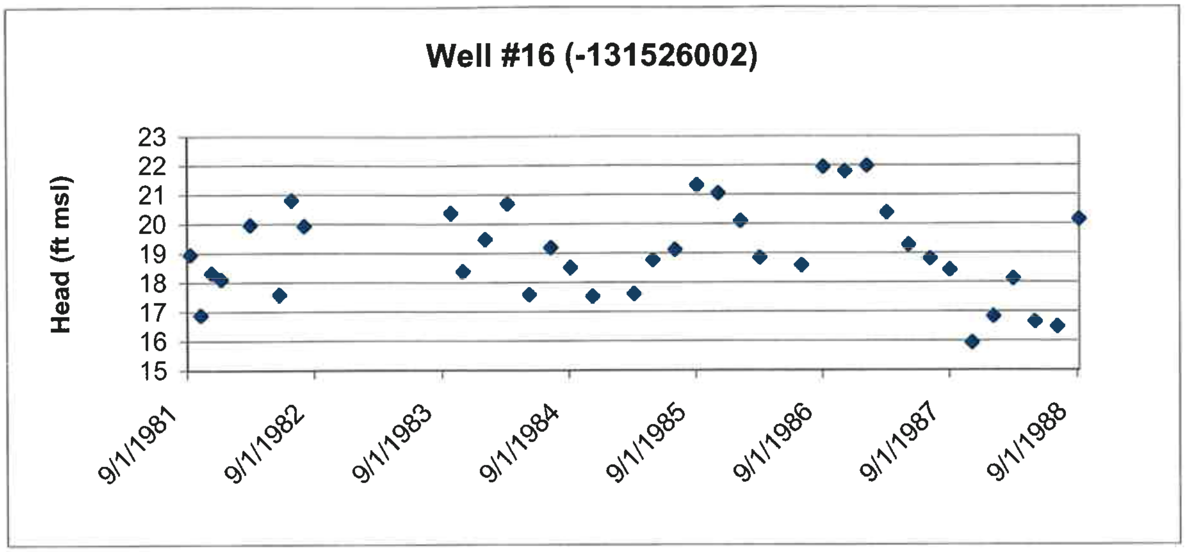
12/1/1985
12/1/1988

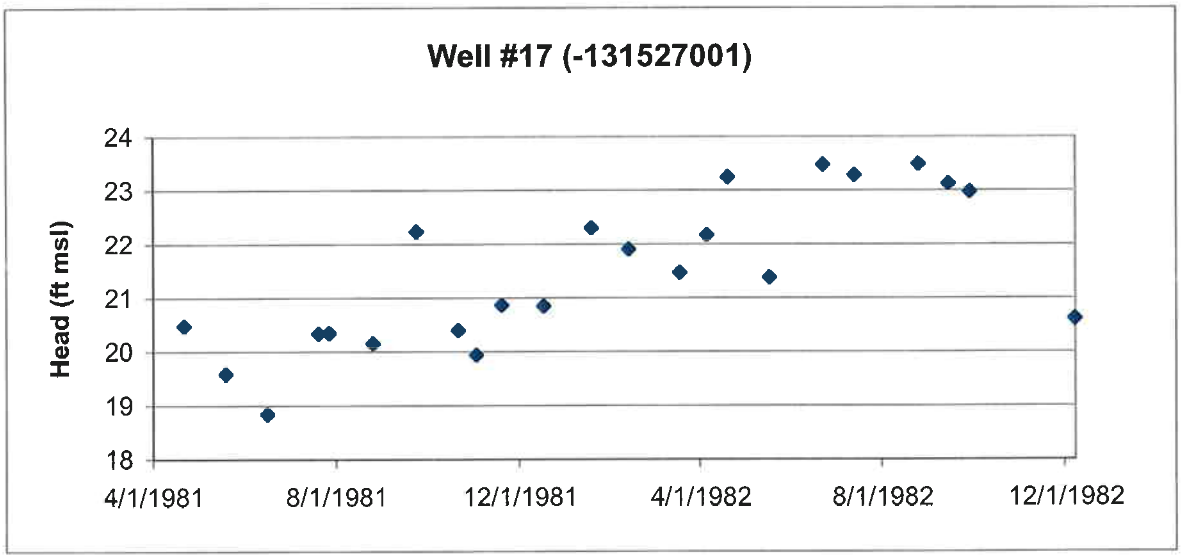

Well #12 (-121528003)
Head (ft msl)
29
28
27
26
25
24
12/1/2001
4/1/2002
8/1/2002
12/1/2002
4/1/2003
8/1/2003
12/1/2003

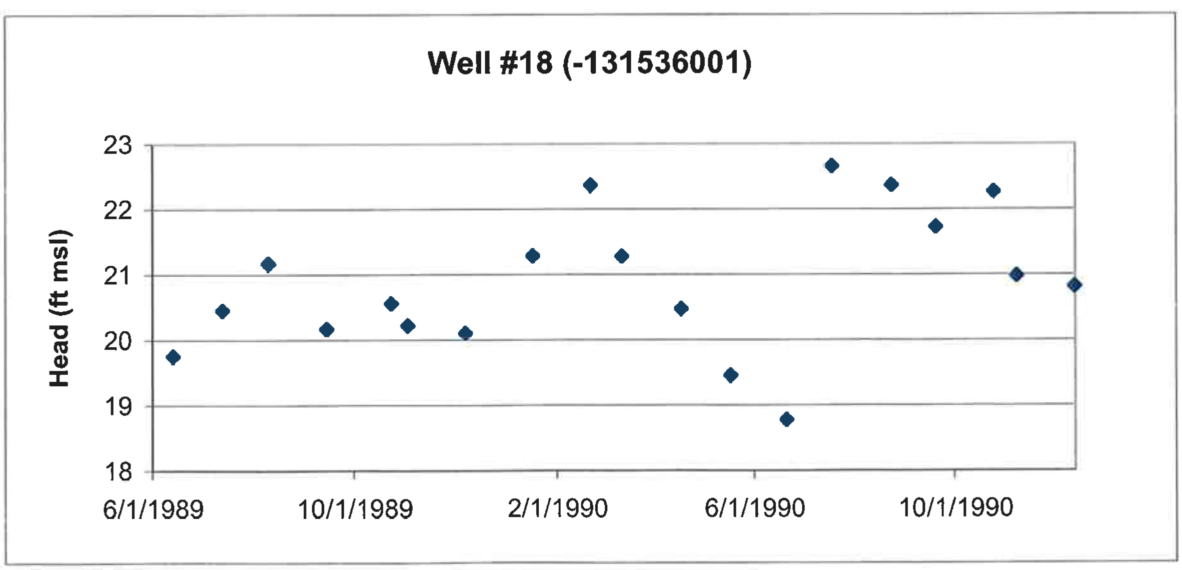

Well #13 (-121717001)
Head (ft msl)
60
56
52
48
44
9/1/1964
9/1/1969
9/1/1974
9/1/1979
9/1/1984
9/1/1989
9/1/1994

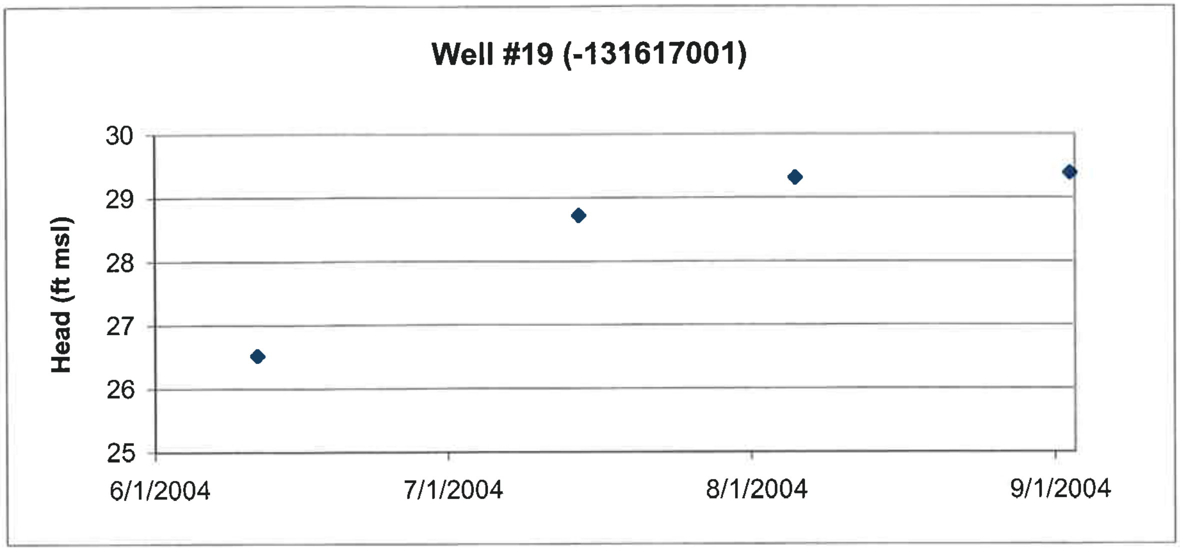

Well #14 (-131506002)
Head (ft msl)
27
26
25
24
23
1/1/1982
3/1/1982
5/1/1982
7/1/1982
9/1/1982
11/1/1982


Well #15 (-131526001)
Head (ft msl)
26
24
22
20
18
16
9/1/1983
9/1/1987
9/1/1991
9/1/1995
9/1/1999
9/1/2003

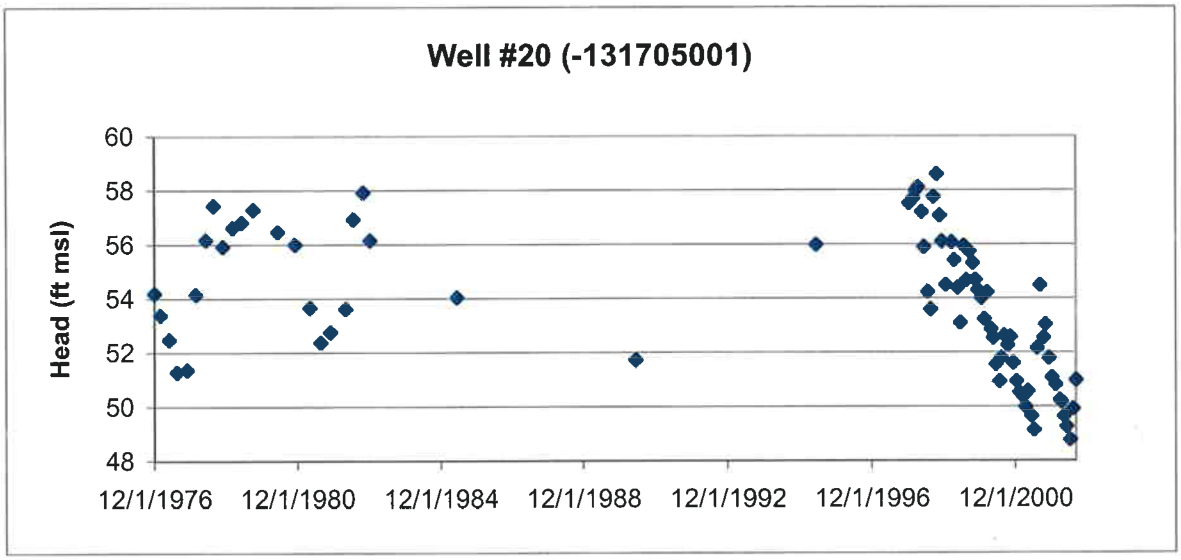

Well #16 (-131526002)
Head (ft msl)
23
22
21
20
19
18
17
16
15
9/1/1981
9/1/1982
9/1/1983
9/1/1984
9/1/1985
9/1/1986
9/1/1987
9/1/1988


Well #17 (-131527001)
Head (ft msl)
24
23
22
21
20
19
18
4/1/1981
8/1/1981
12/1/1981
4/1/1982
8/1/1982
12/1/1982

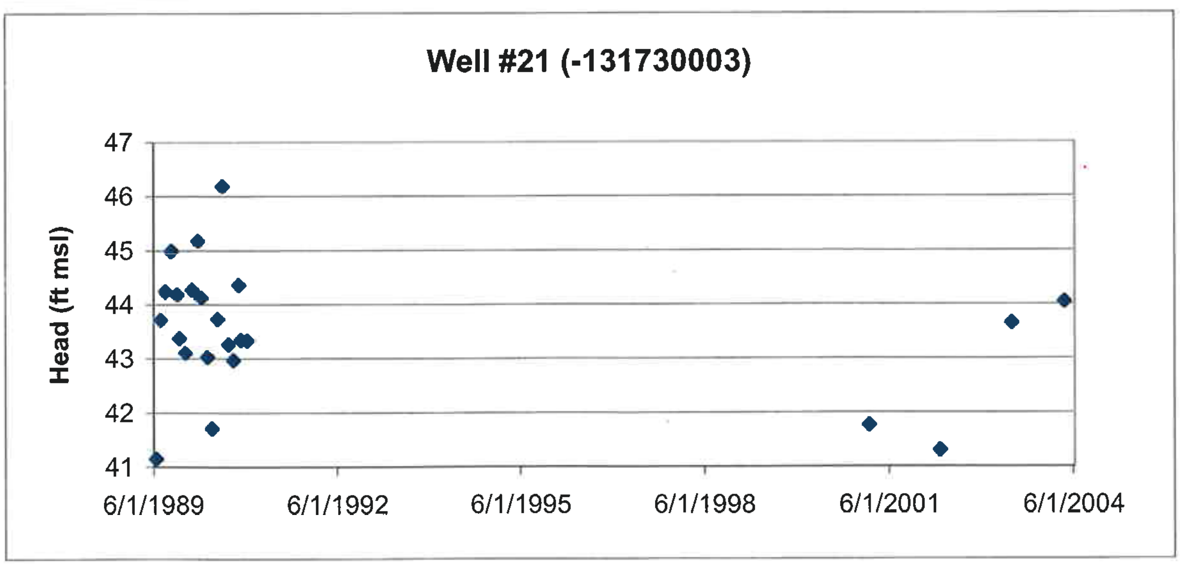

Well #18 (-131536001)
Head (ft msl)
23
22
21
20
19
18
6/1/1989
10/1/1989
2/1/1990
6/1/1990
10/1/1990



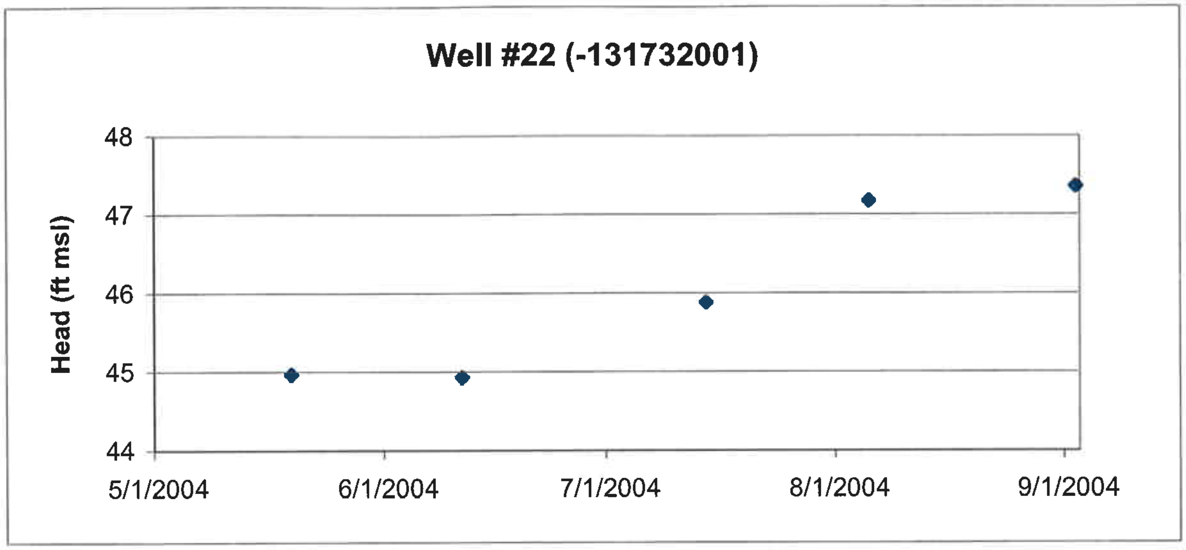
Well #19 (-131617001)
Head (ft msl)
30
29
28
27
26
25
6/1/2004
7/1/2004
8/1/2004
9/1/2004

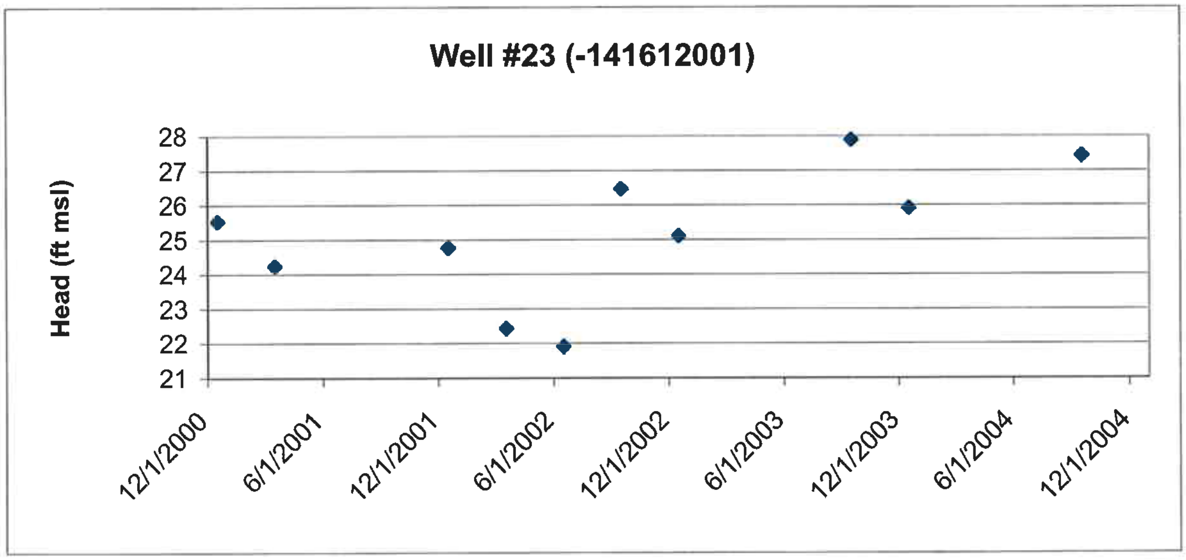


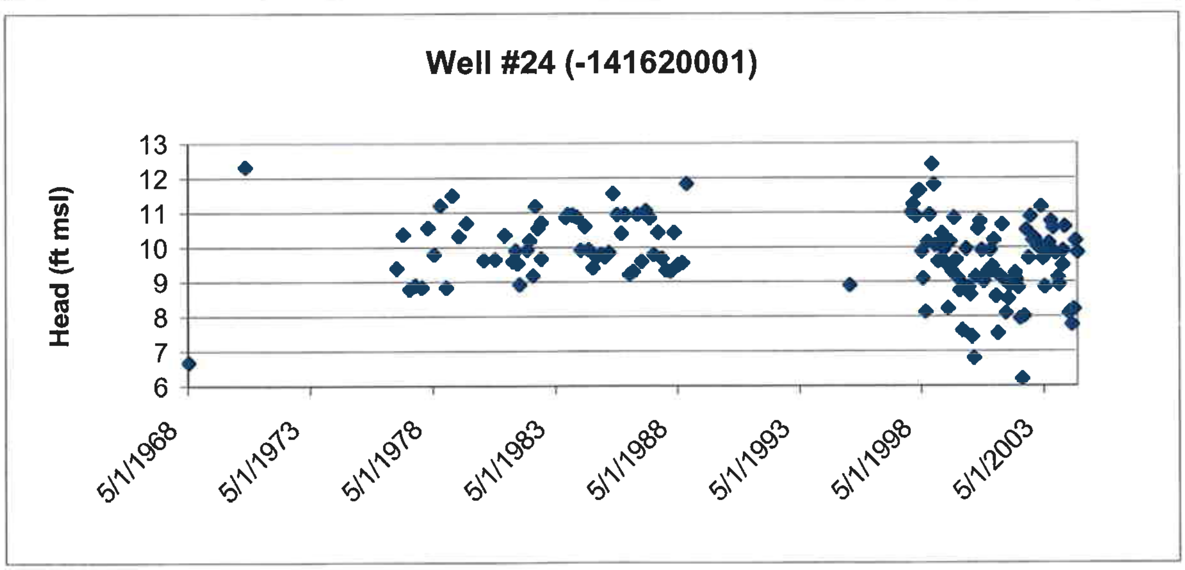
Well #20 (-131705001)
Head (ft msl)
60
58
56
54
52
50
48
12/1/1976
12/1/1980
12/1/1984
12/1/1988
12/1/1992
12/1/1996
12/1/2000

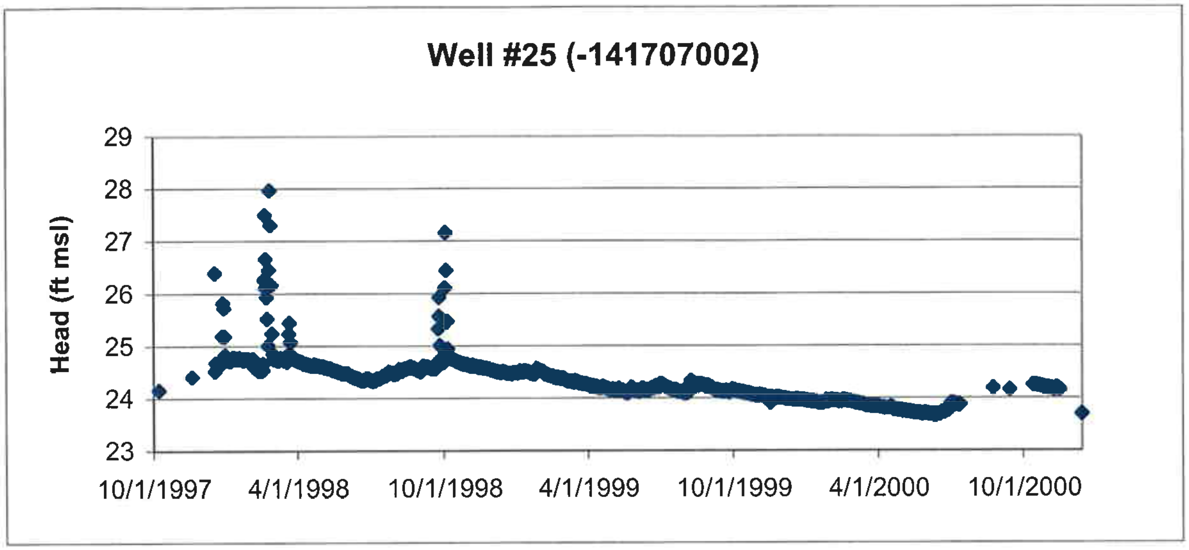


Well #21 (-131730003)
Head (ft msl)
47
46
45
44
43
42
41
6/1/1989
6/1/1992
6/1/1995
6/1/1998
6/1/2001
6/1/2004

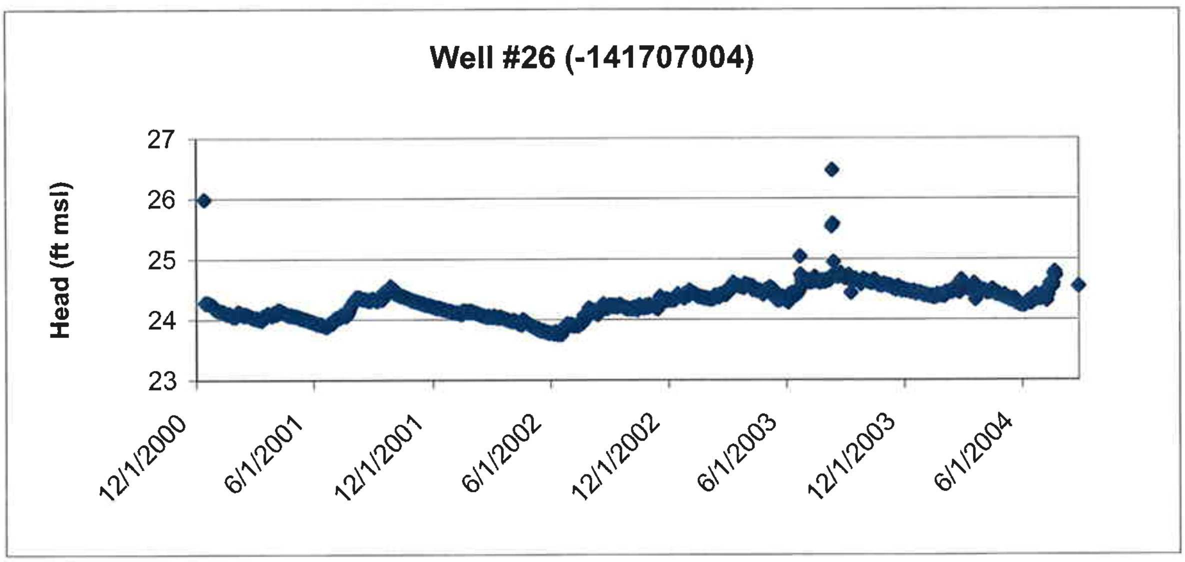

Well #22 (-131732001)
Head (ft msl)
48
47
46
45
44
5/1/2004
6/1/2004
7/1/2004
8/1/2004
9/1/2004


Well #23 (-141612001)
Head (ft msl)
28
27
26
25
24
23
22
21
12/1/2000
6/1/2001
12/1/2001
6/1/2002
12/1/2002
6/1/2003
12/1/2003
6/1/2004
12/1/2004

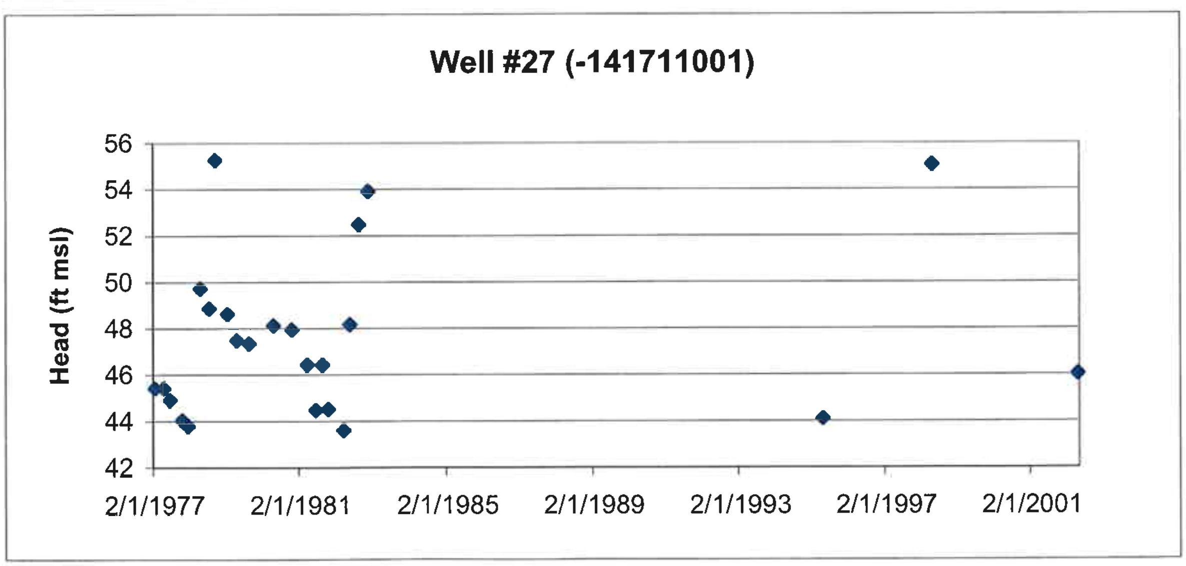

Well #24 (-141620001)
Head (ft msl)
13
12
11
10
9
8
7
6
5/1/1968
5/1/1973
5/1/1978
5/1/1983
5/1/1988
5/1/1993
5/1/1998
5/1/2003



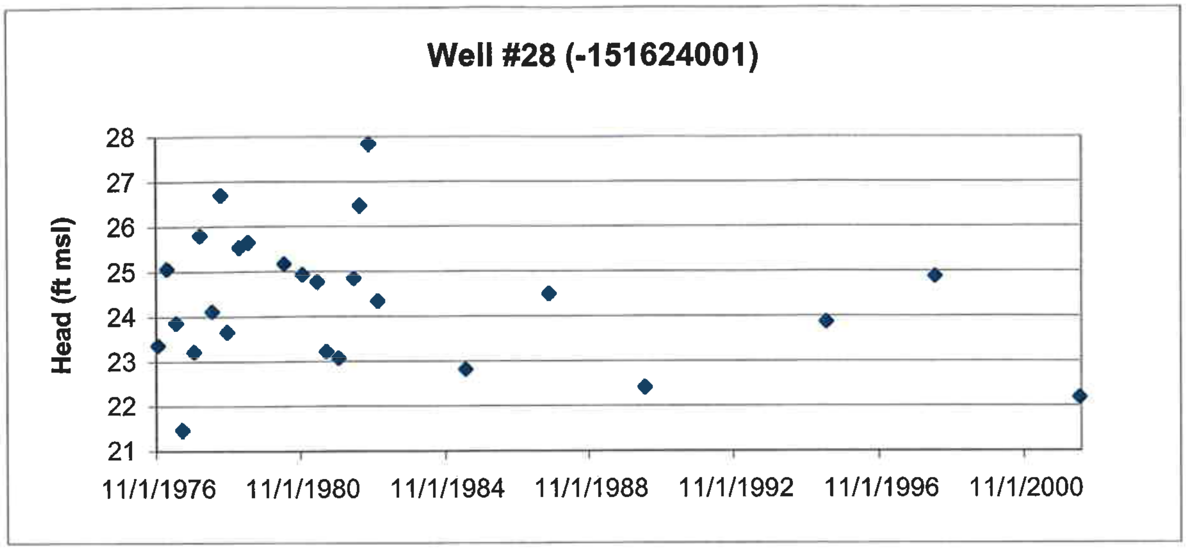
Well #25 (-141707002)
Head (ft msl)
29
28
27
26
25
24
23
10/1/1997
4/1/1998
10/1/1998
4/1/1999
10/1/1999
4/1/2000
10/1/2000

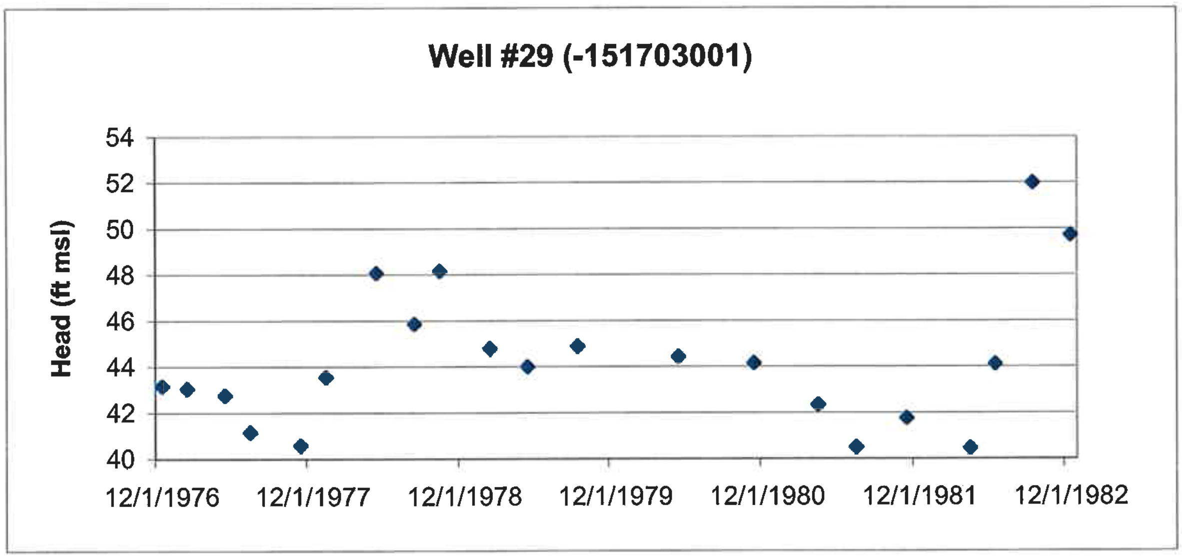


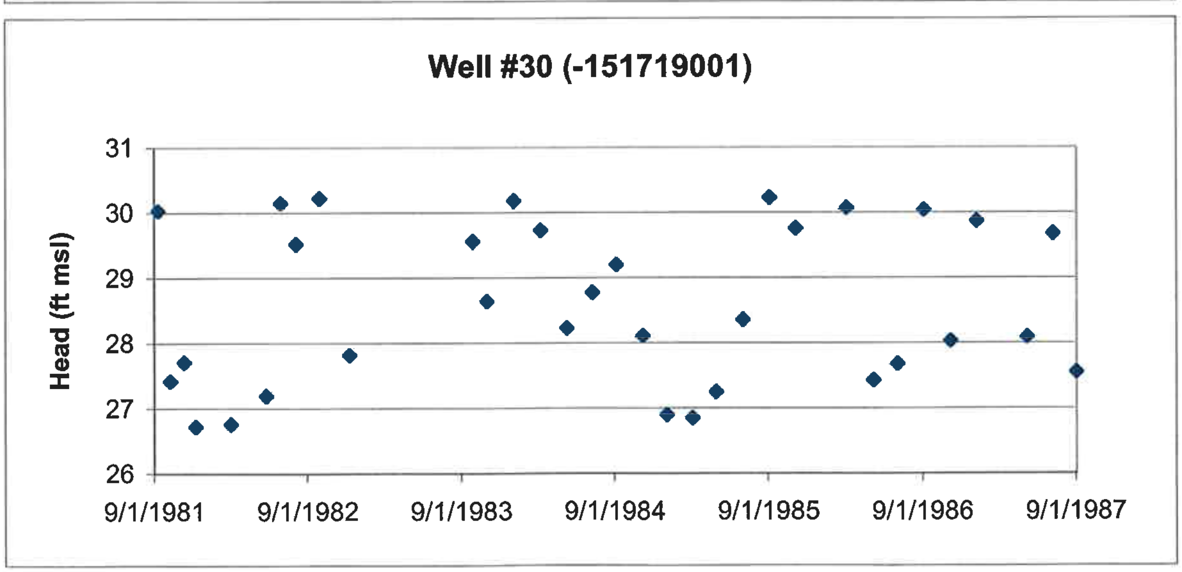
Well #26 (-141707004)
Head (ft msl)
27
26
25
24
23
12/1/2000
6/1/2001
12/1/2001
6/1/2002
12/1/2002
6/1/2003
12/1/2003
6/1/2004

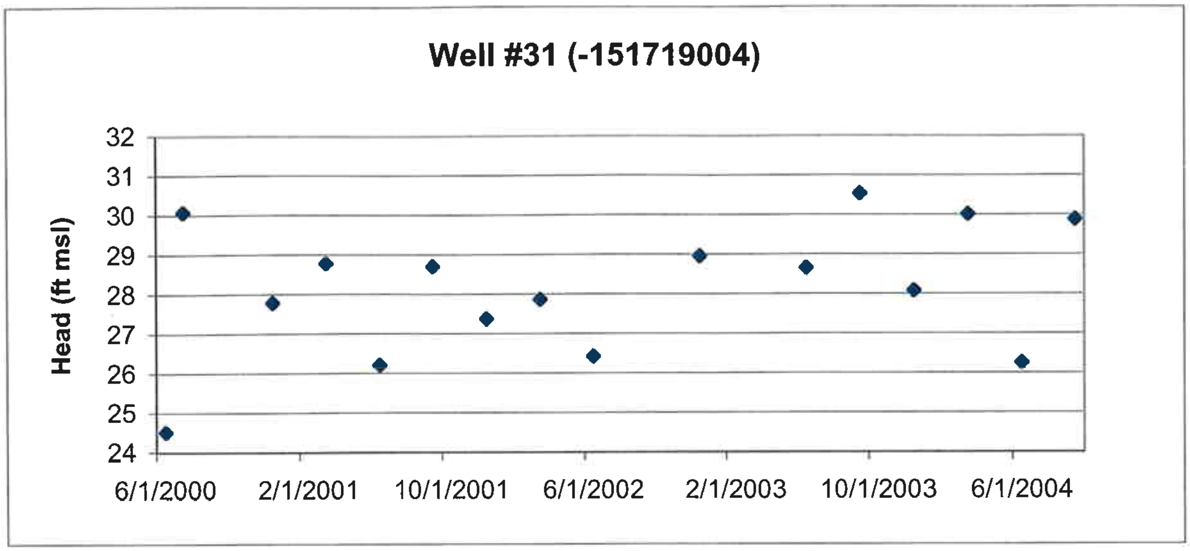


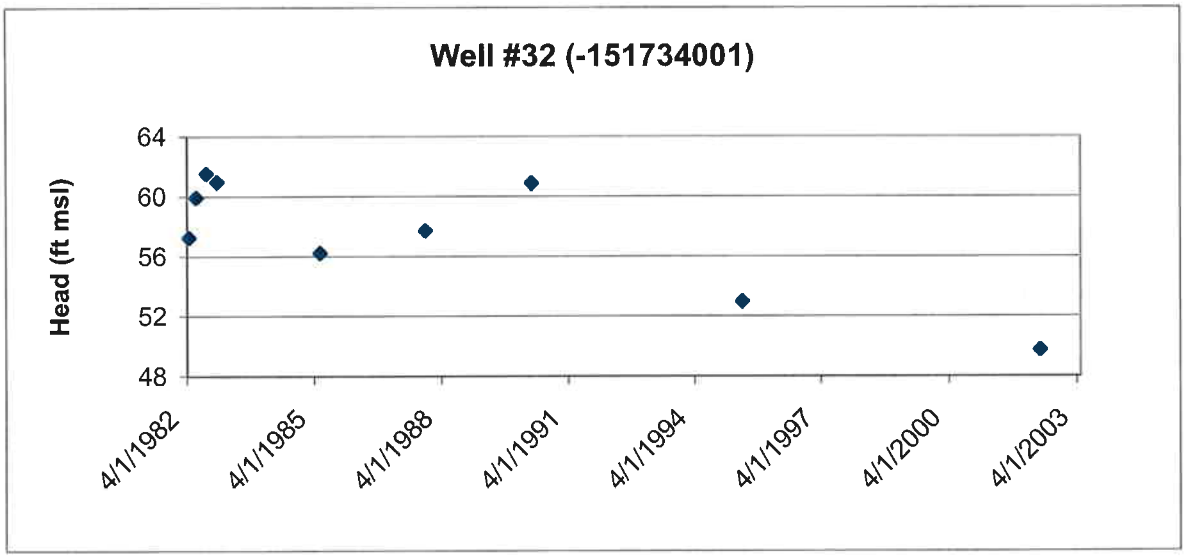
Well #27 (-141711001)
Head (ft msl)
56
54
52
50
48
46
44
42
2/1/1977
2/1/1981
2/1/1985
2/1/1989
2/1/1993
2/1/1997
2/1/2001

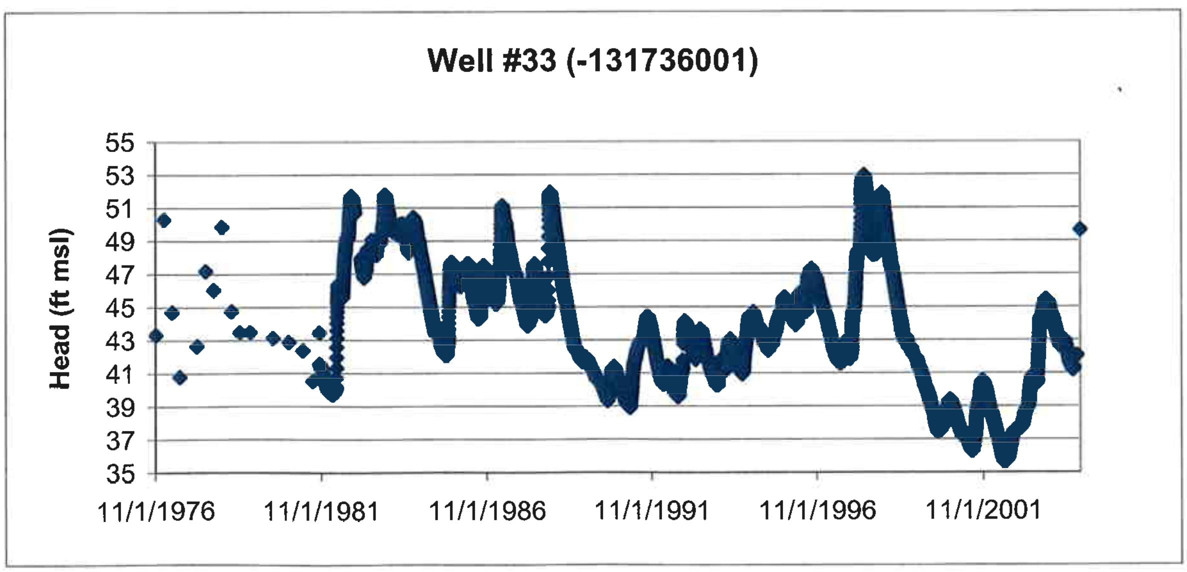

Well #28 (-151624001)
Head (ft msl)
28
27
26
25
24
23
22
21
11/1/1976
11/1/1980
11/1/1984
11/1/1988
11/1/1992
11/1/1996
11/1/2000

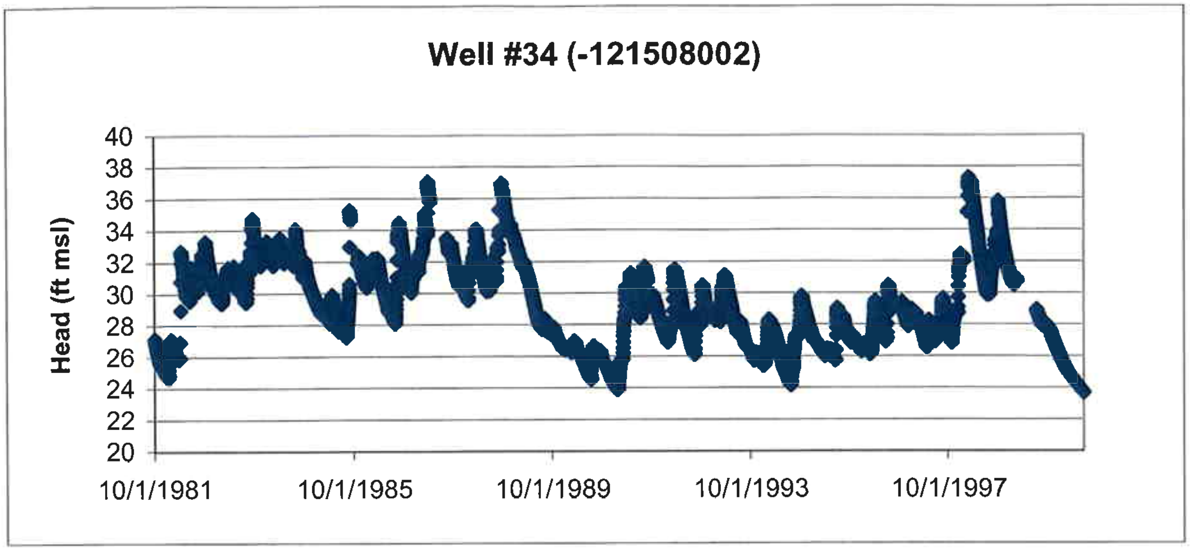

Well #29 (-151703001)
Head (ft msl)
54
52
50
48
46
44
42
40
12/1/1976
12/1/1977
12/1/1978
12/1/1979
12/1/1980
12/1/1981
12/1/1982

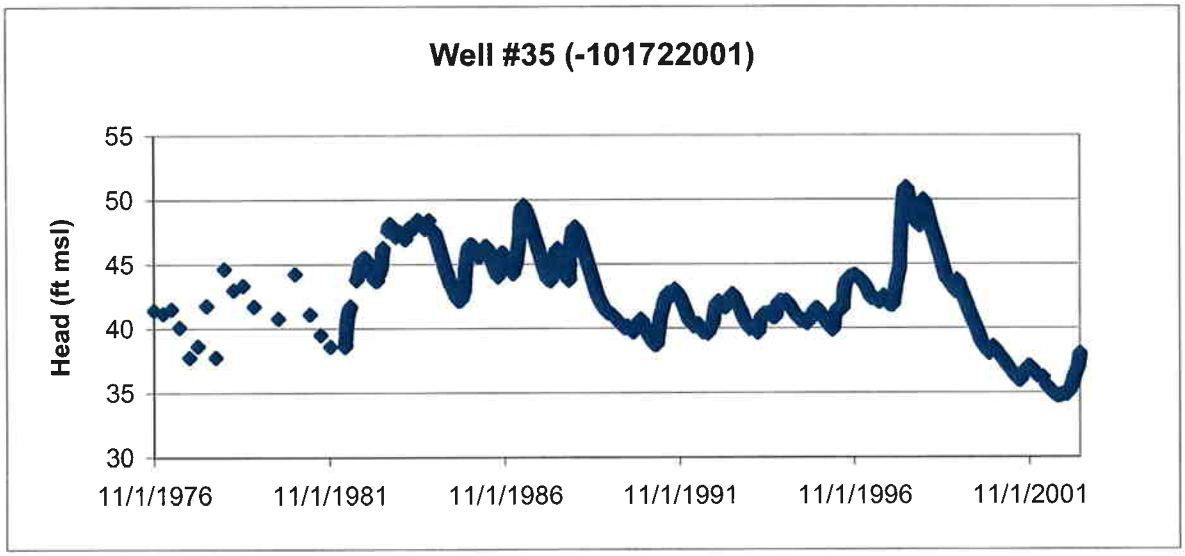

Well #30 (-151719001)
Head (ft msl)
31
30
29
28
27
26
9/1/1981
9/1/1982
9/1/1983
9/1/1984
9/1/1985
9/1/1986
9/1/1987

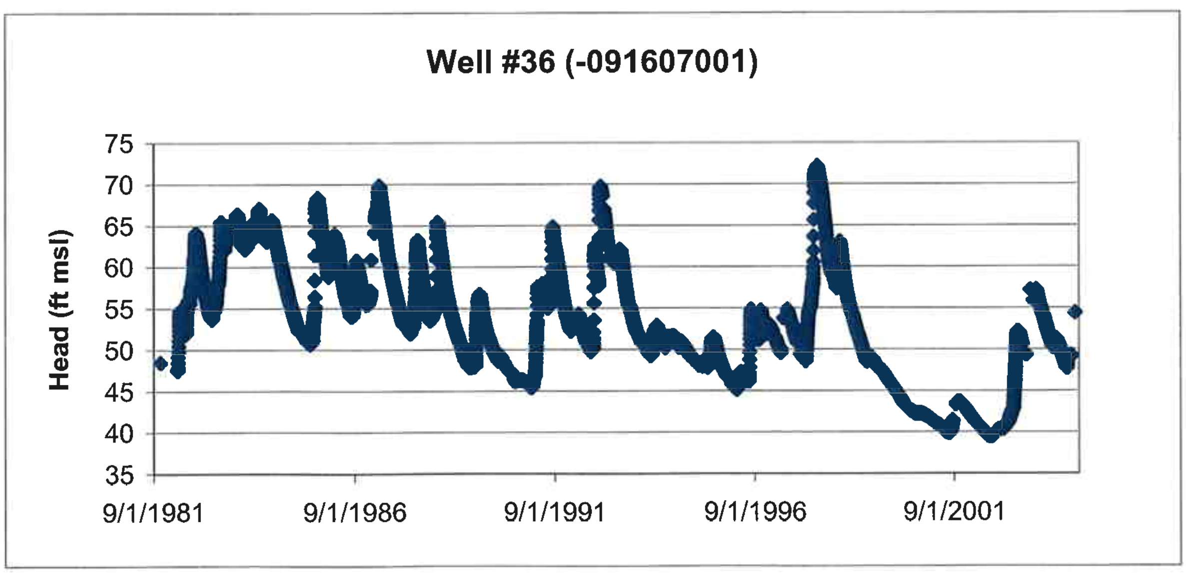

Well #31 (-151719004)
Head (ft msl)
32
31
30
29
28
27
26
25
24
6/1/2000
2/1/2001
10/1/2001
6/1/2002
2/1/2003
10/1/2003
6/1/2004


Well #32 (-151734001)
Head (ft msl)
64
60
56
52
48
4/1/1982
4/1/1985
4/1/1988
4/1/1991
4/1/1994
4/1/1997
4/1/2000
4/1/2003


Well #33 (-131736001)
Head (ft msl)
55
53
51
49
47
45
43
41
39
37
35
11/1/1976
11/1/1981
11/1/1986
11/1/1991
11/1/1996
11/1/2001

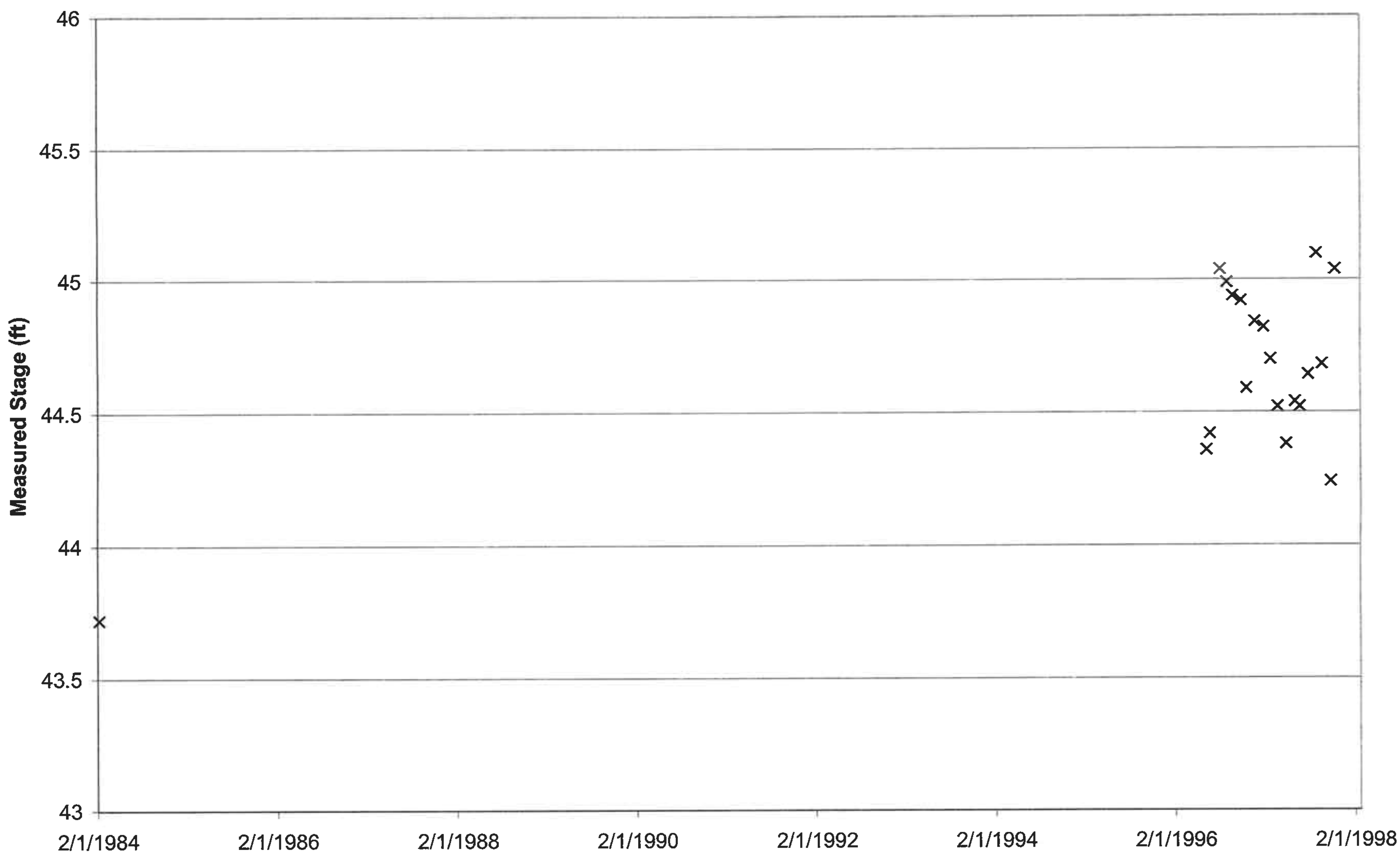

Well #34 (-121508002)
Head (ft msl)
40
38
36
34
32
30
28
26
24
22
20
10/1/1981
10/1/1985
10/1/1989
10/1/1993
10/1/1997


Well #35 (-101722001)
Head (ft msl)
55
50
45
40
35
30
11/1/1976
11/1/1981
11/1/1986
11/1/1991
11/1/1996
11/1/2001

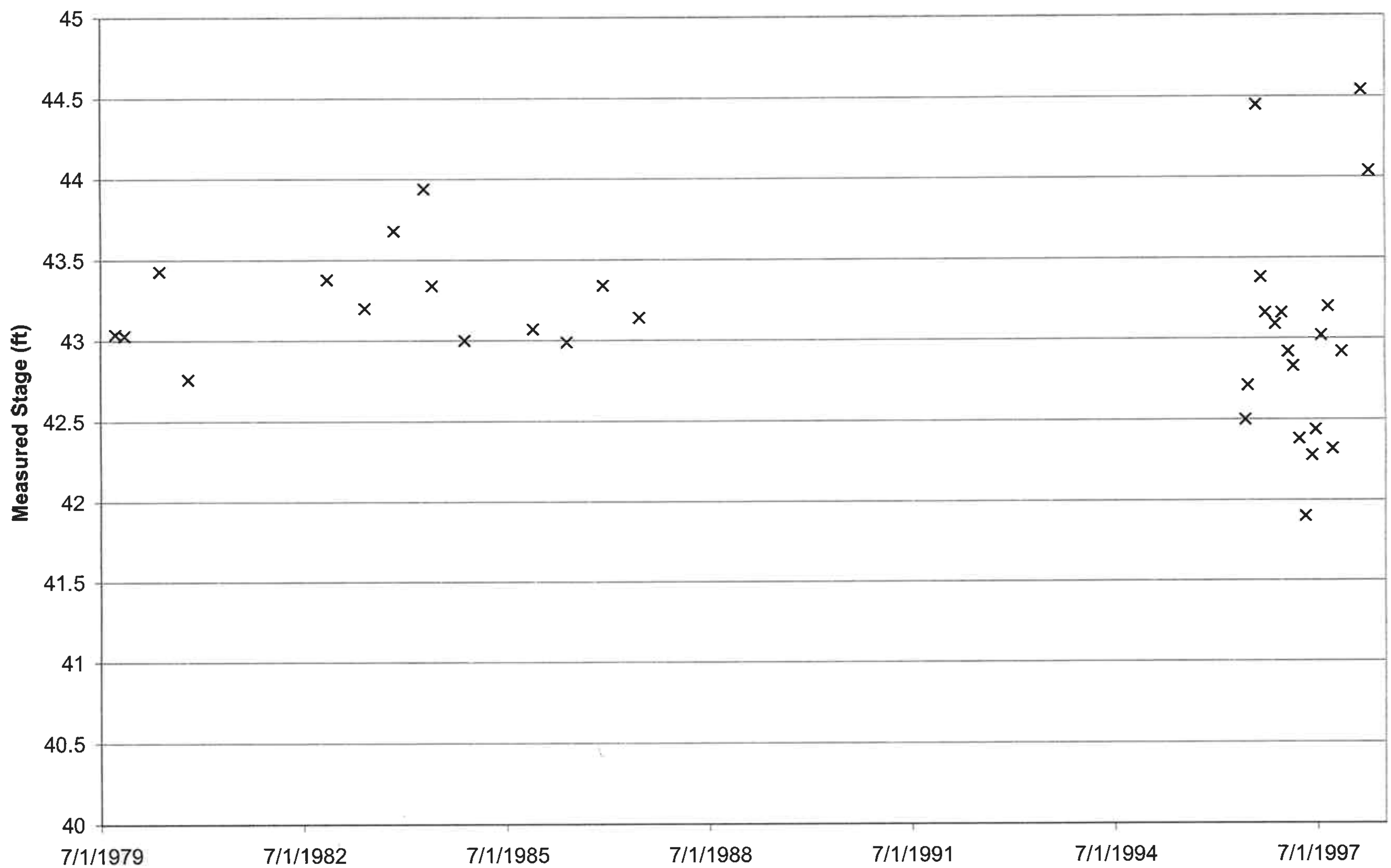

Well #36 (-091607001)
Head (ft msl)
75
70
65
60
55
50
45
40
35
9/1/1981
9/1/1986
9/1/1991
9/1/1996
9/1/2001

APPENDIX B

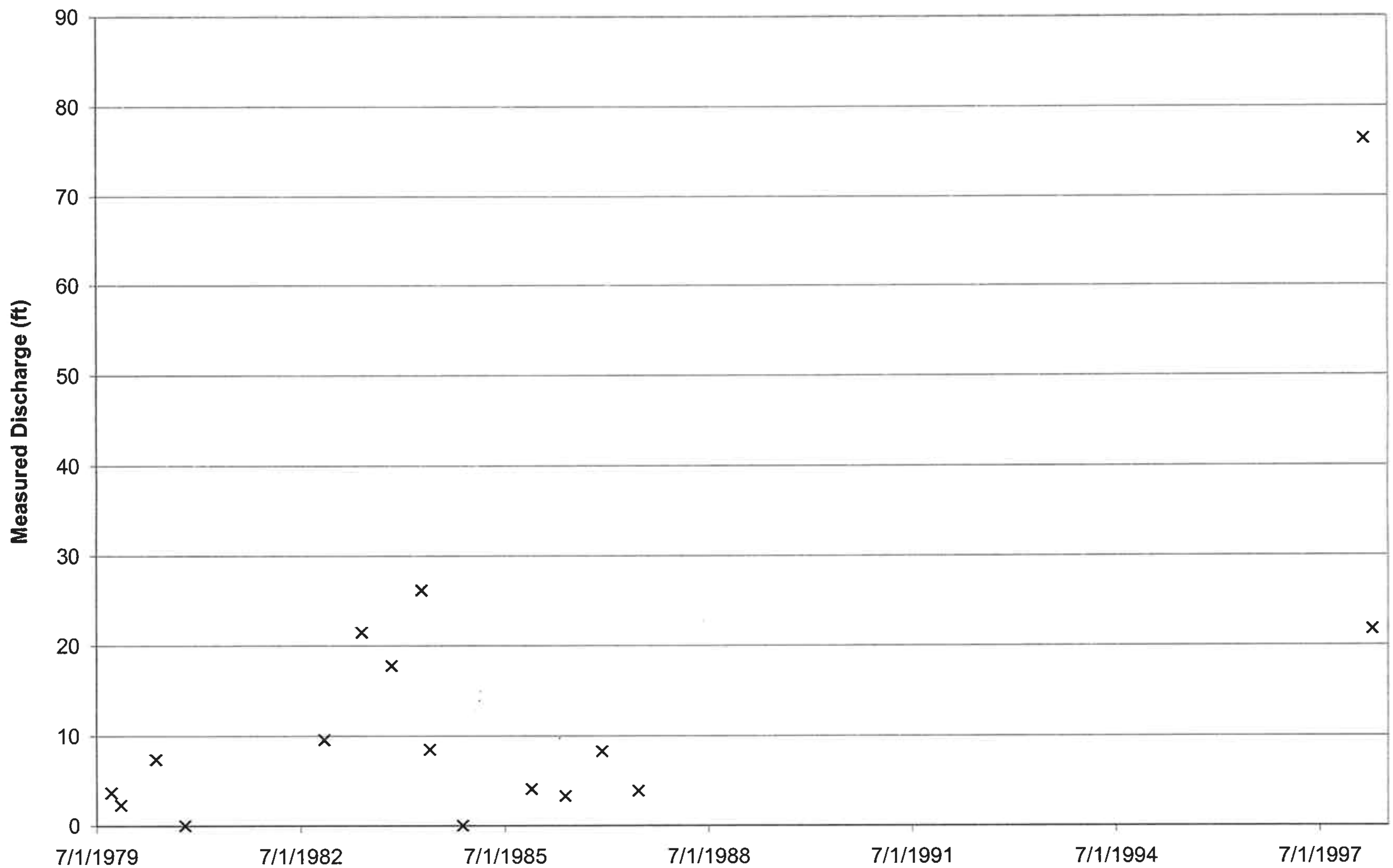
02313400 WACCASASSA RIVER NEAR BRONSON

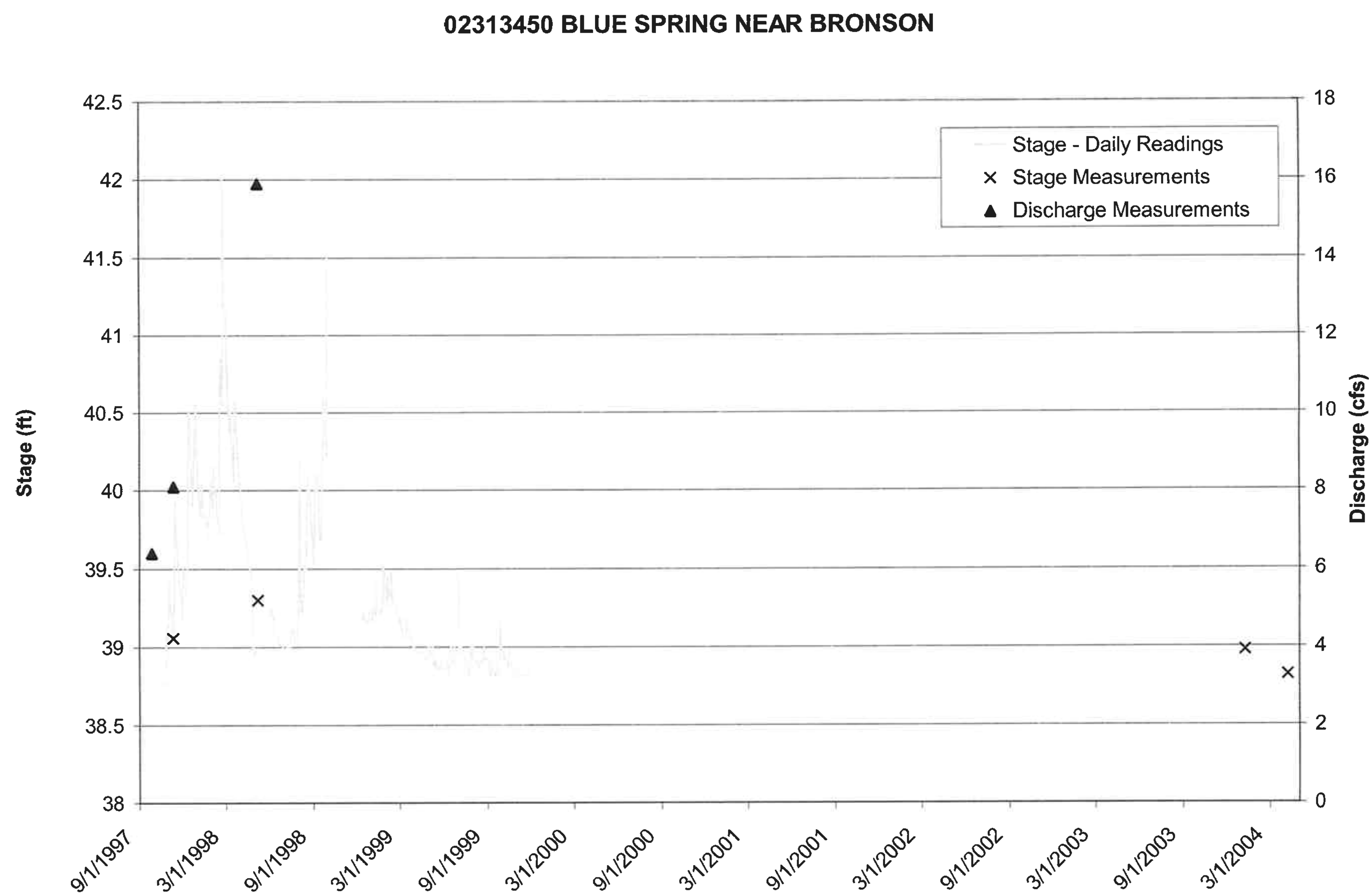


02313448 LITTLE WACCASASSA RIVER NEAR BRONSON

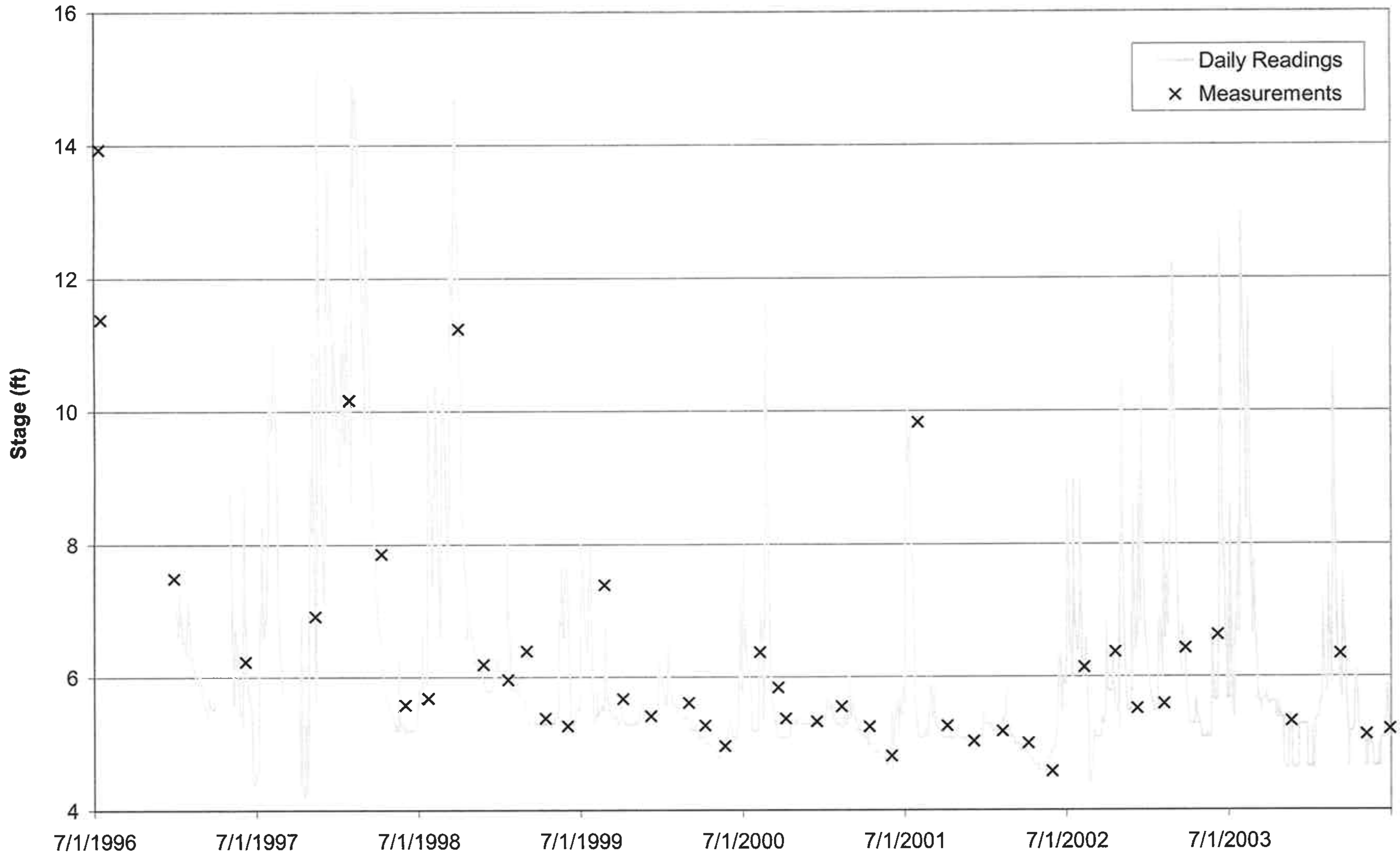


02313448 LITTLE WACCASASSA RIVER NEAR BRONSON

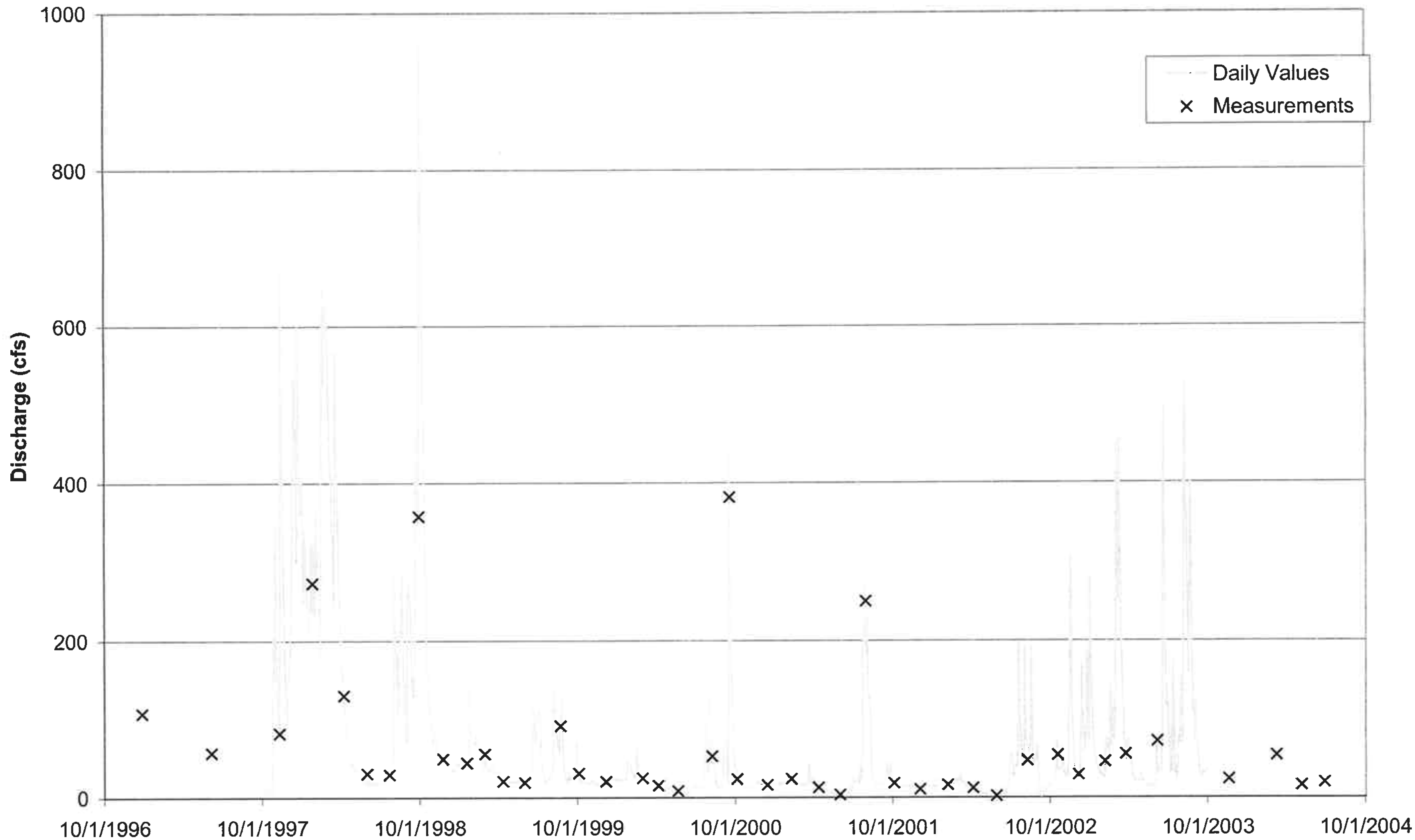



02313450 BLUE SPRING NEAR BRONSON
Stage (ft)
Discharge (cfs)
Stage - Daily Readings
Stage Measurements
Discharge Measurements
42.5
42
41.5
41
40.5
40
39.5
39
38.5
38
18
16
14
12
10
8
6
4
2
0
9/1/1997
3/1/1998
9/1/1998
3/1/1999
9/1/1999
3/1/2000
9/1/2000
3/1/2001
9/1/2001
3/1/2002
9/1/2002
3/1/2003
9/1/2003
3/1/2004

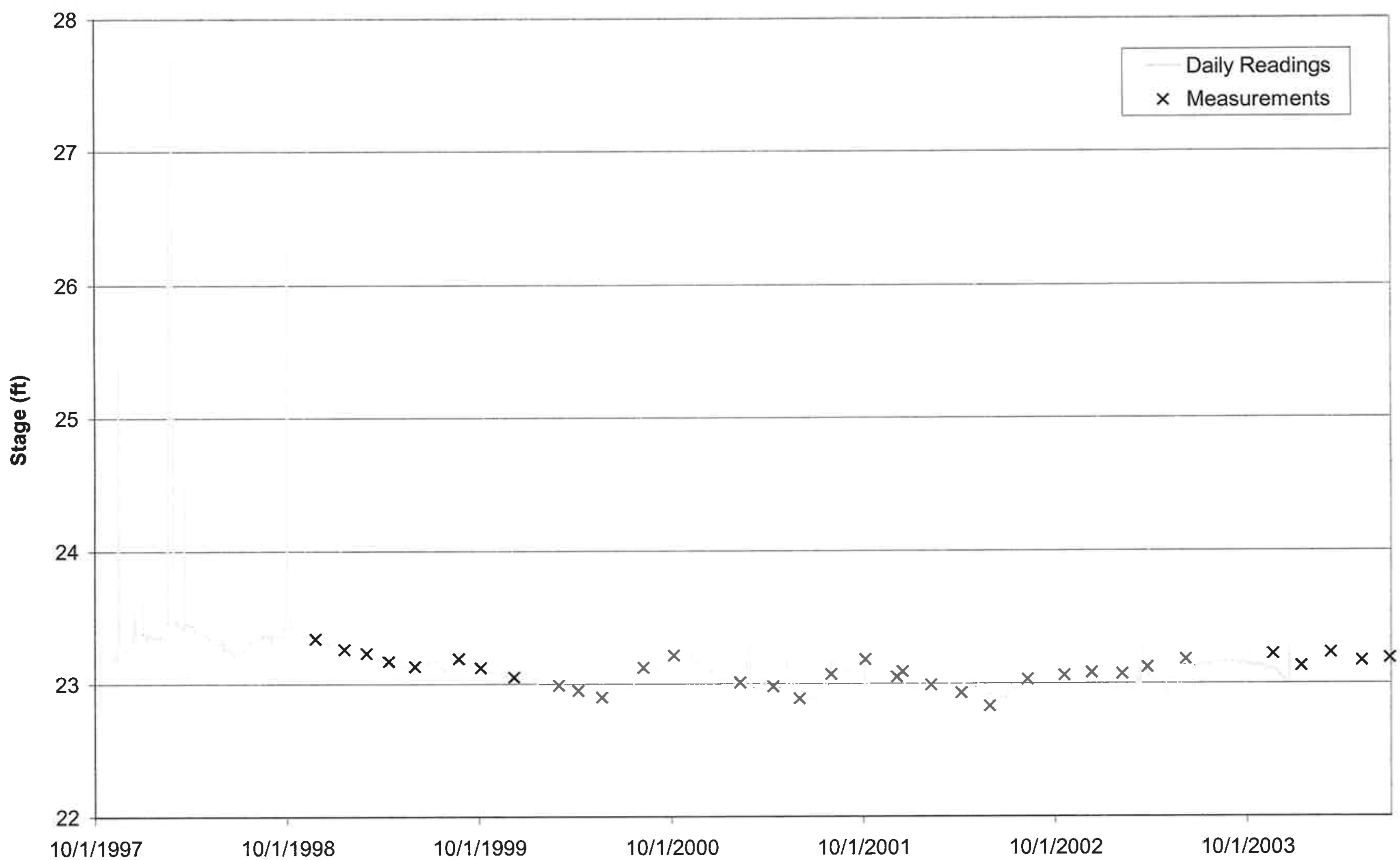
02313530 WACCASASSA RIVER AT GULF HAMMOCK AT US 19



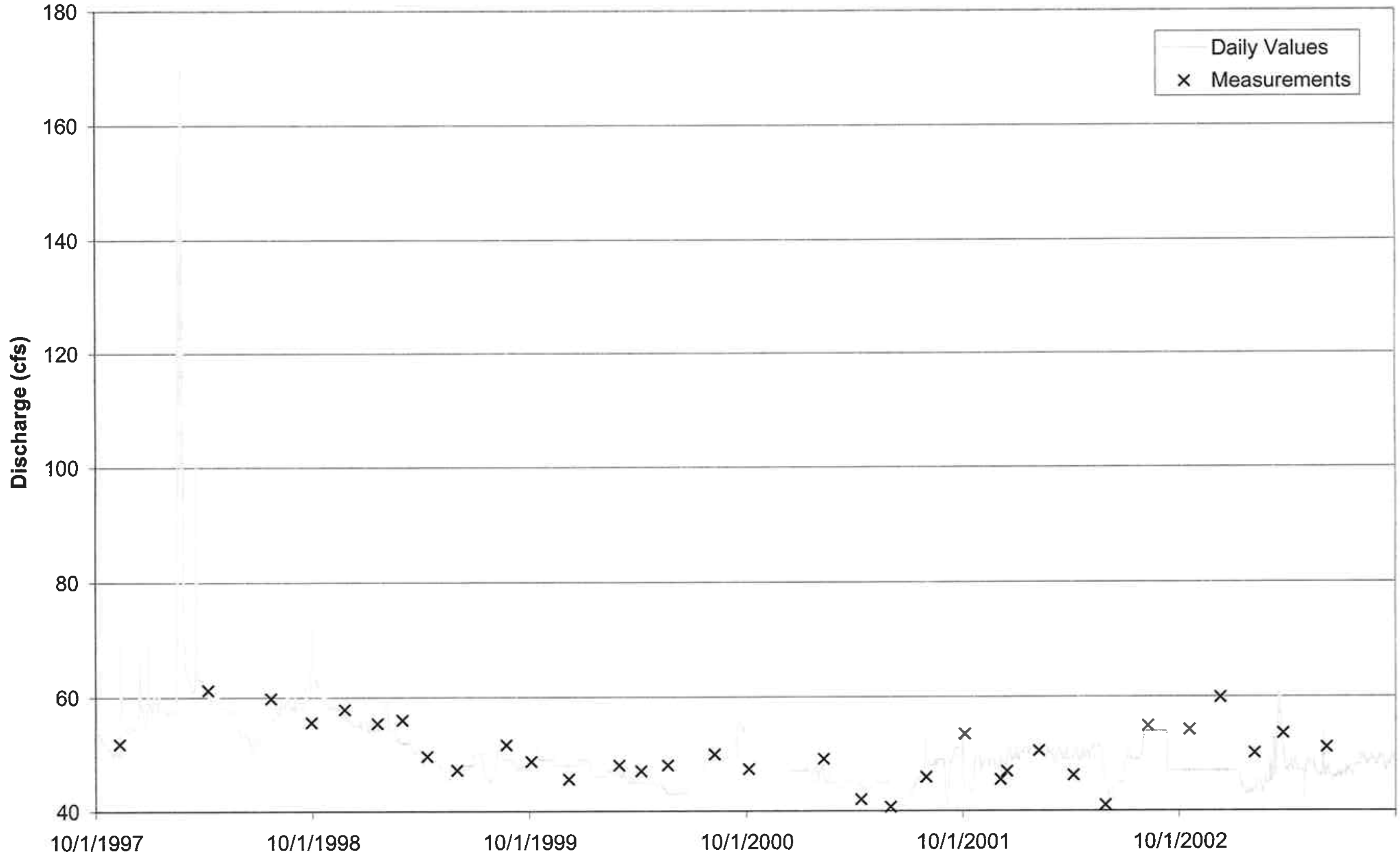
02313530 WACCASASSA RIVER AT GULF HAMMOCK AT US 19

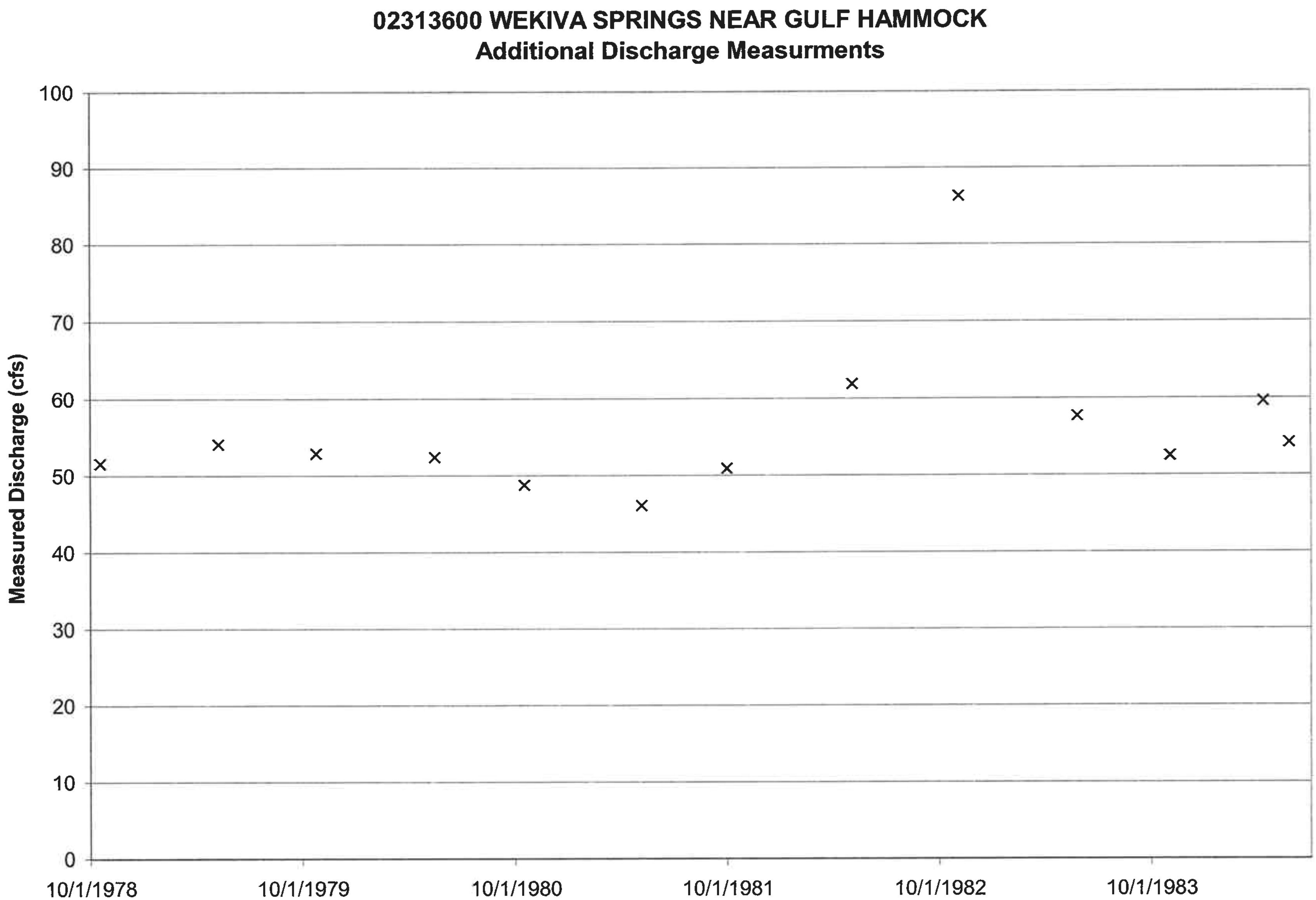


02313600 WEKIVA SPRINGS NEAR GULF HAMMOCK

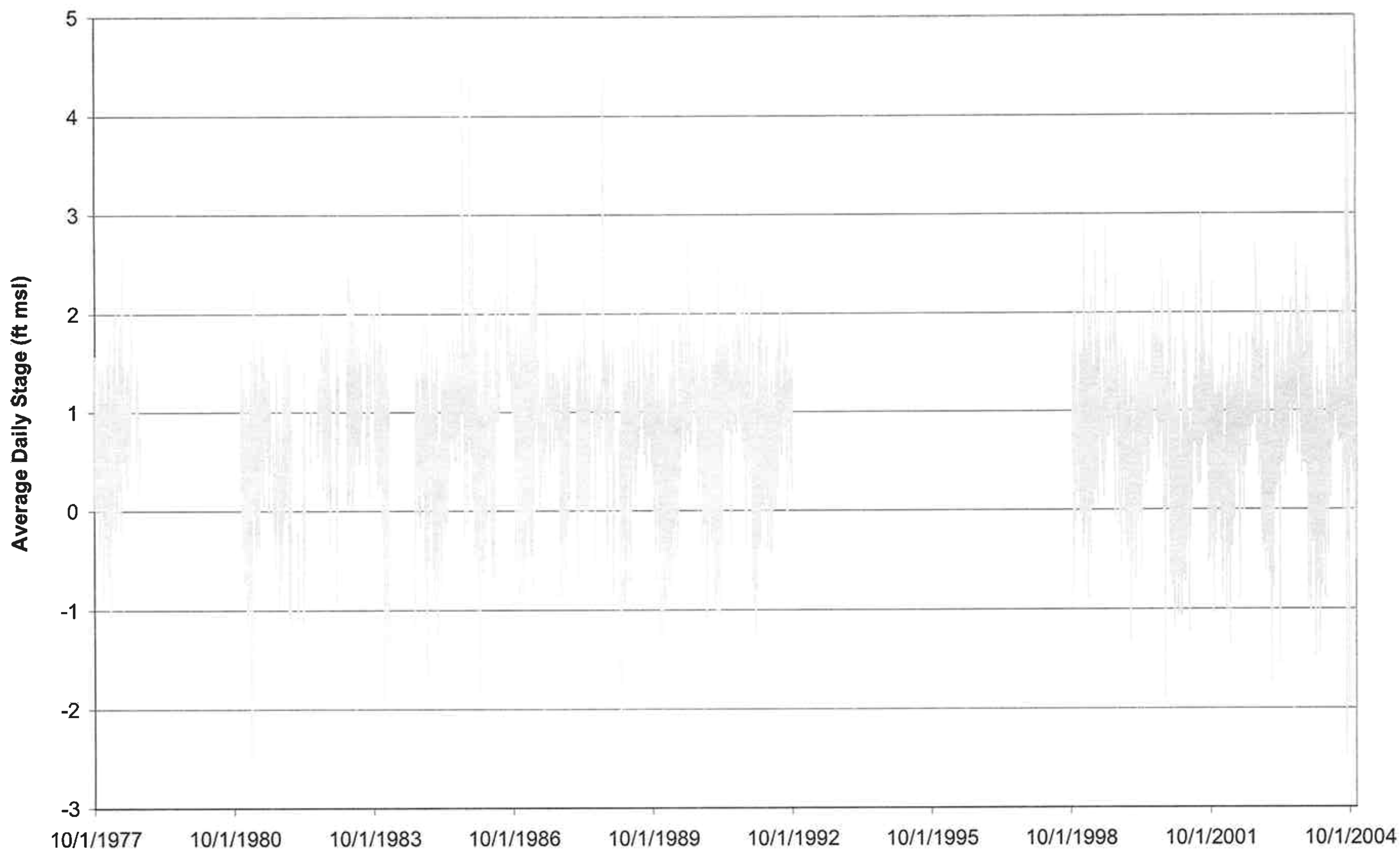


02313600 WEKIVA SPRINGS NEAR GULF HAMMOCK

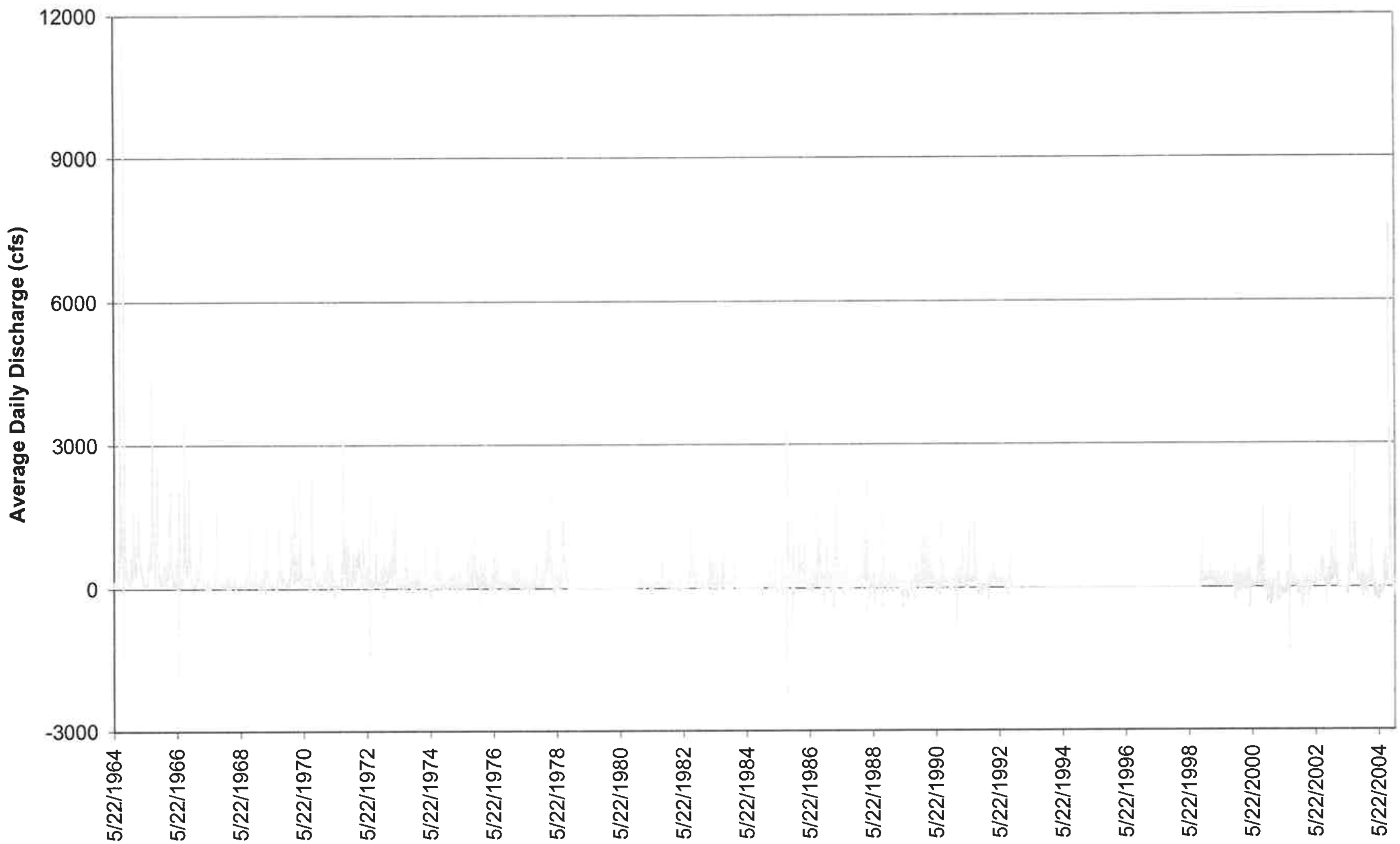



02313600 WEKIVA SPRINGS NEAR GULF HAMMOCK
Additional Discharge Measurments
Measured Discharge (cfs)
100
90
80
70
60
50
40
30
20
10
0
10/1/1978
10/1/1979
10/1/1980
10/1/1981
10/1/1982
10/1/1983

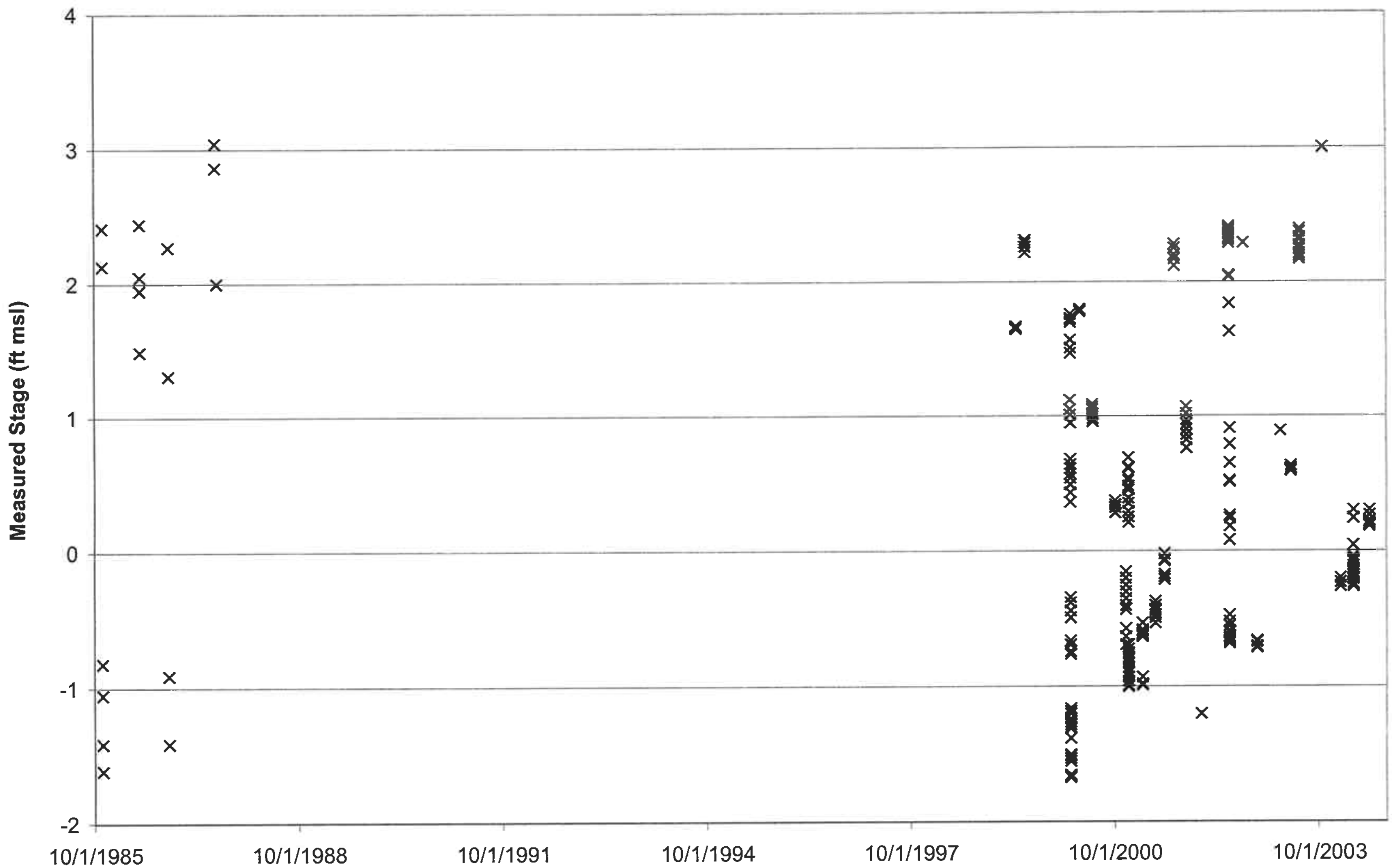
02313700 WACCASASSA RIVER NEAR GULF HAMMOCK



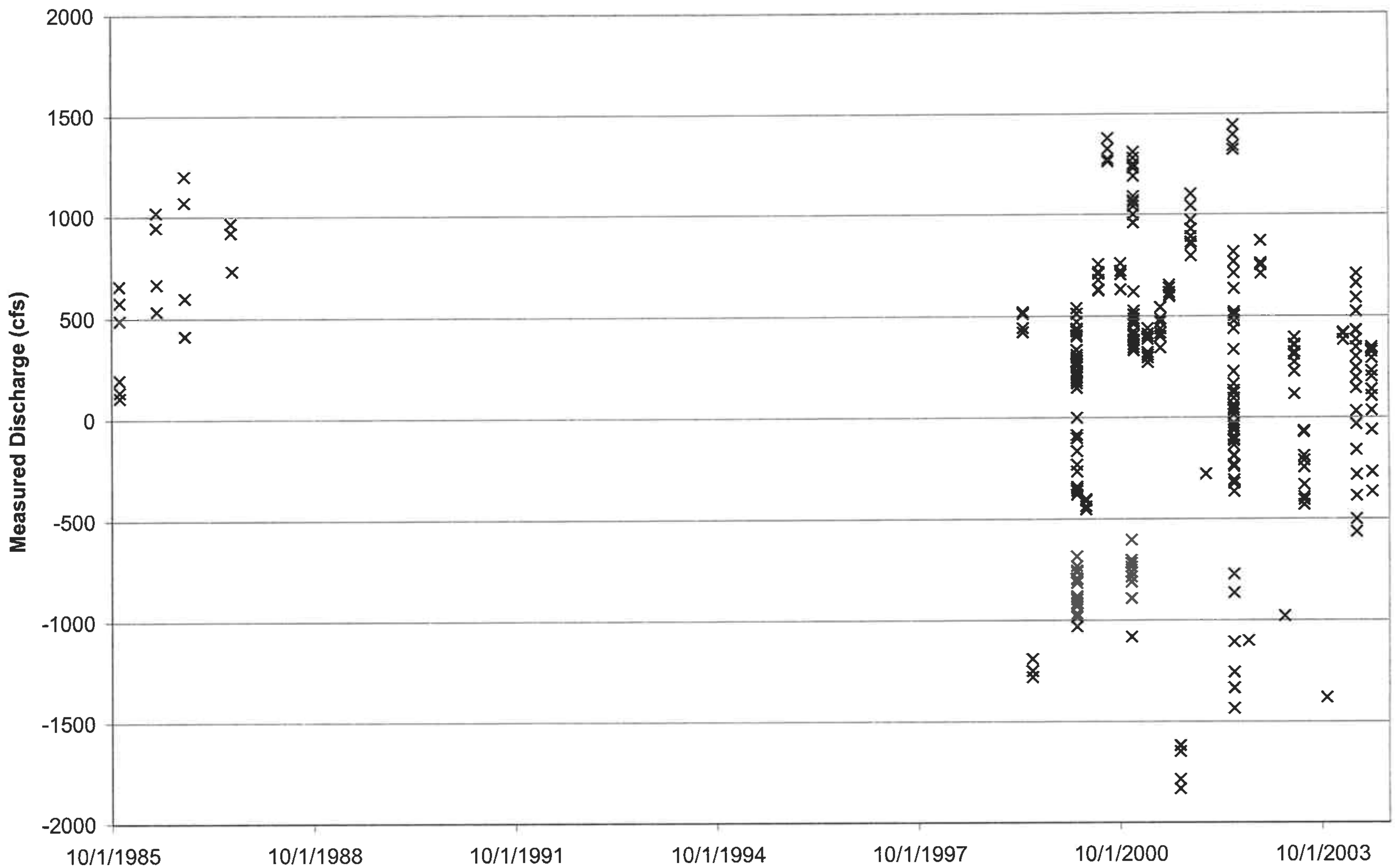
02313700 WACCASASSA RIVER NEAR GULF HAMMOCK



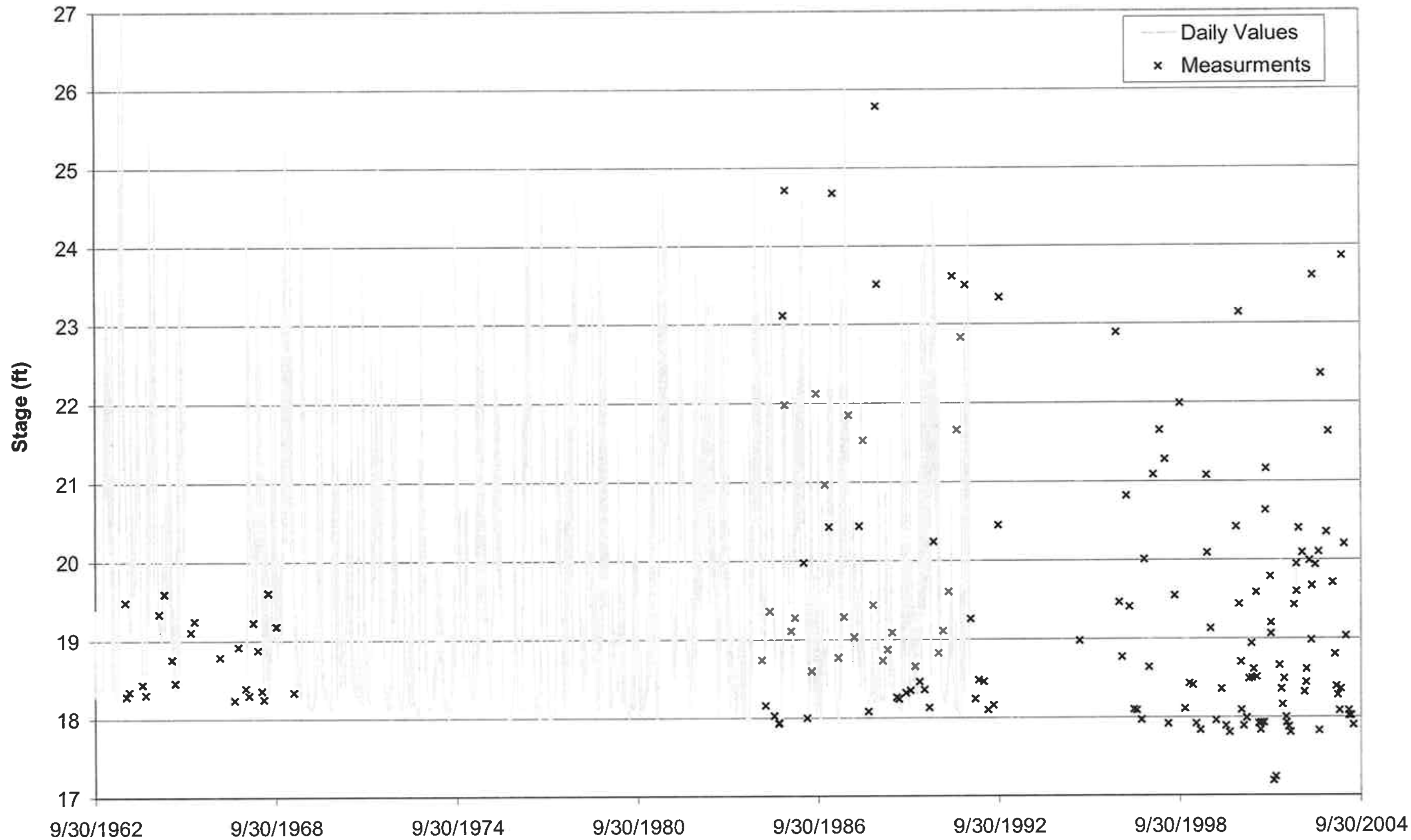
02313700 WACCASASSA RIVER NEAR GULF HAMMOCK



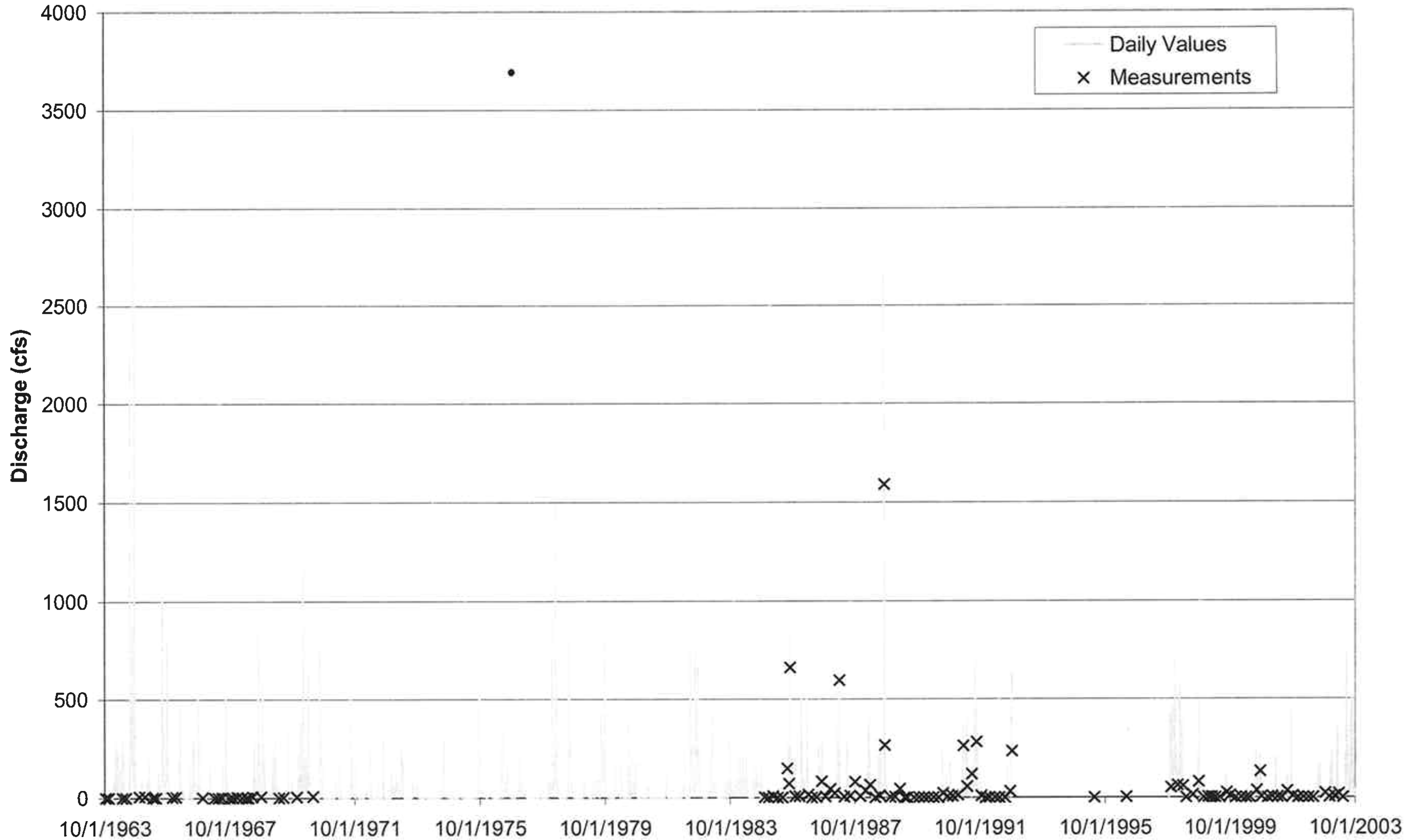
02313700 WACCASASSA RIVER NEAR GULF HAMMOCK



02314200 TENMILE CREEK AT LEBANON STATION

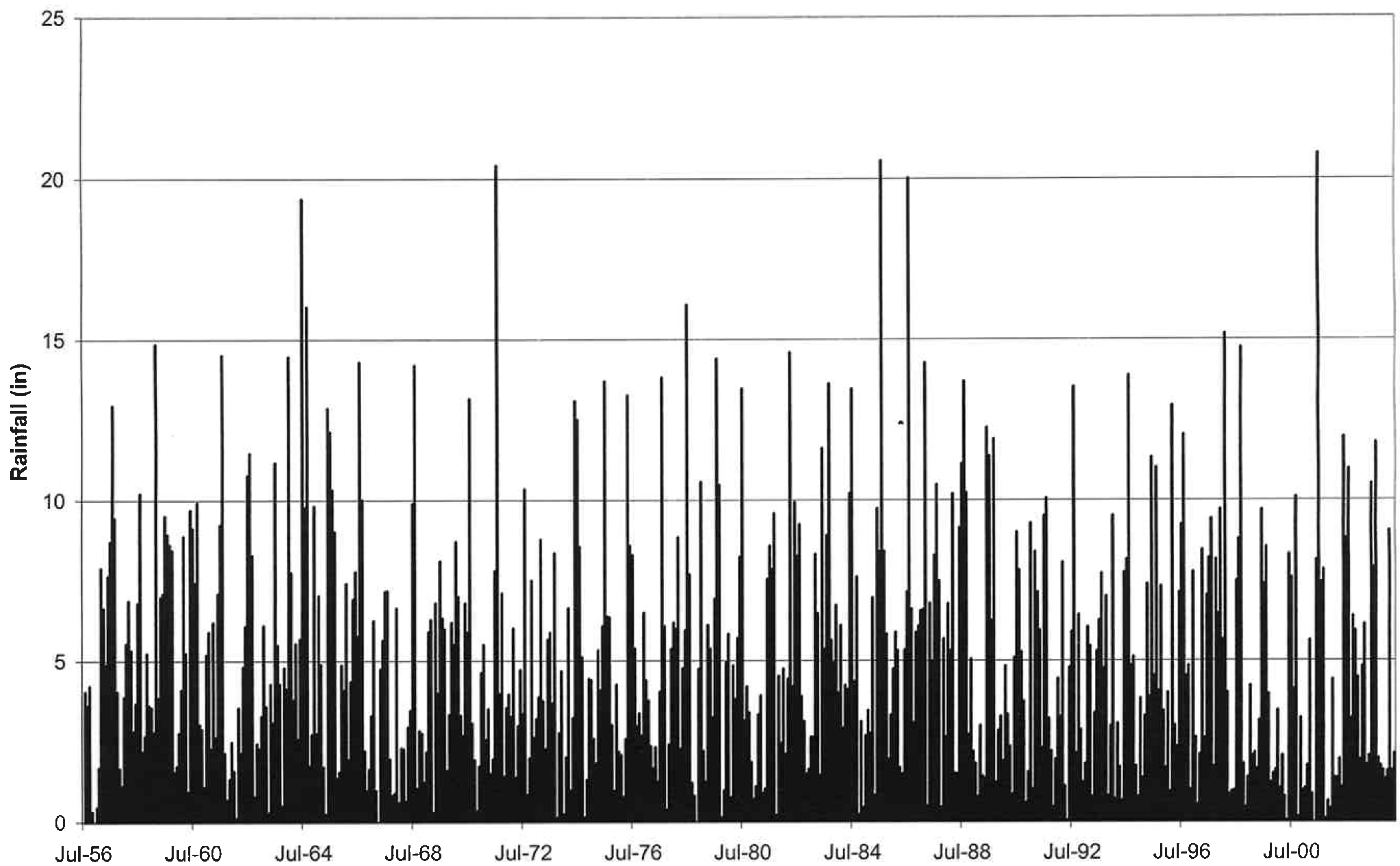


02314200 TENMILE CREEK AT LEBANON STATION

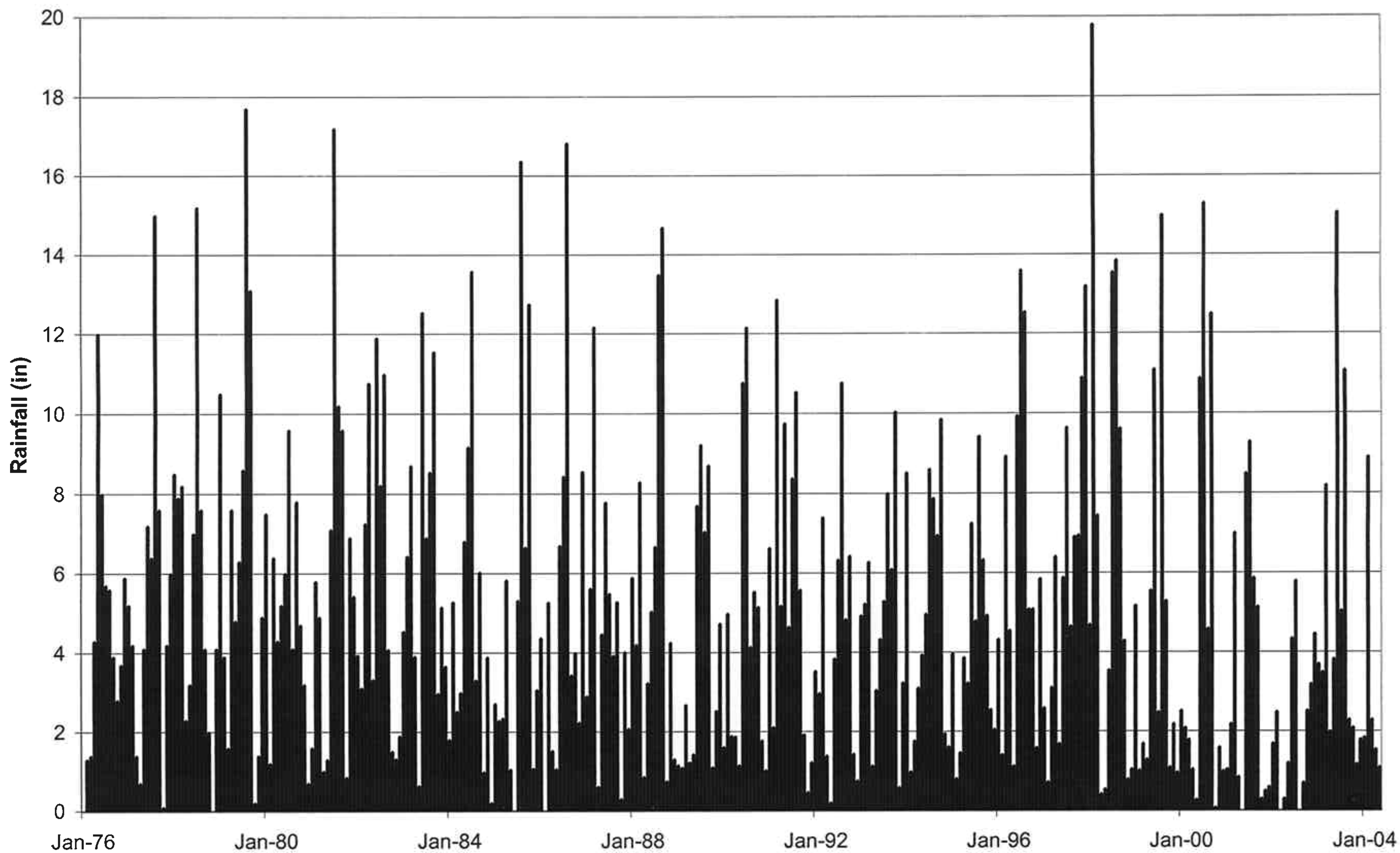


APPENDIX C

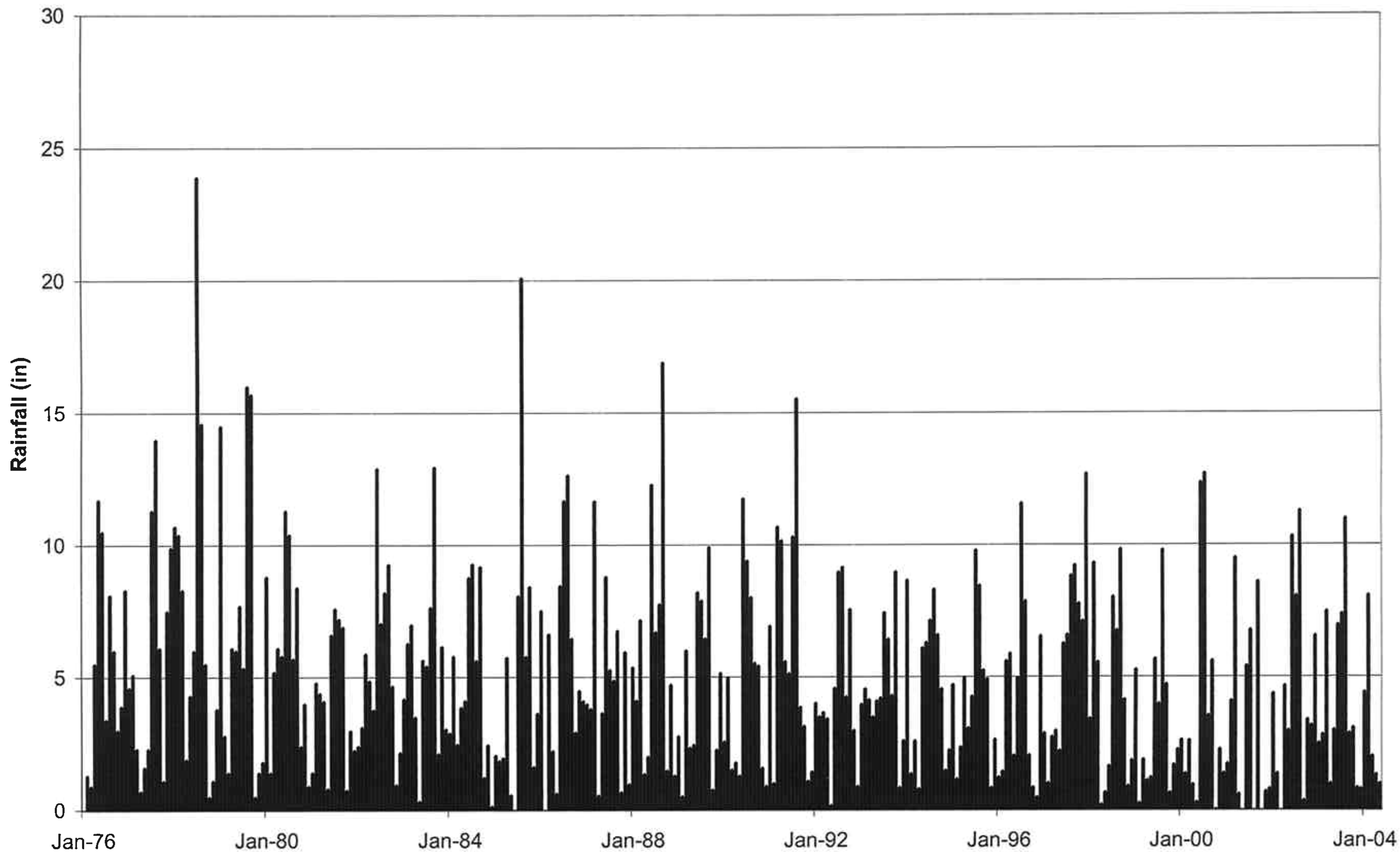
Usher Tower Monthly Rainfall Totals



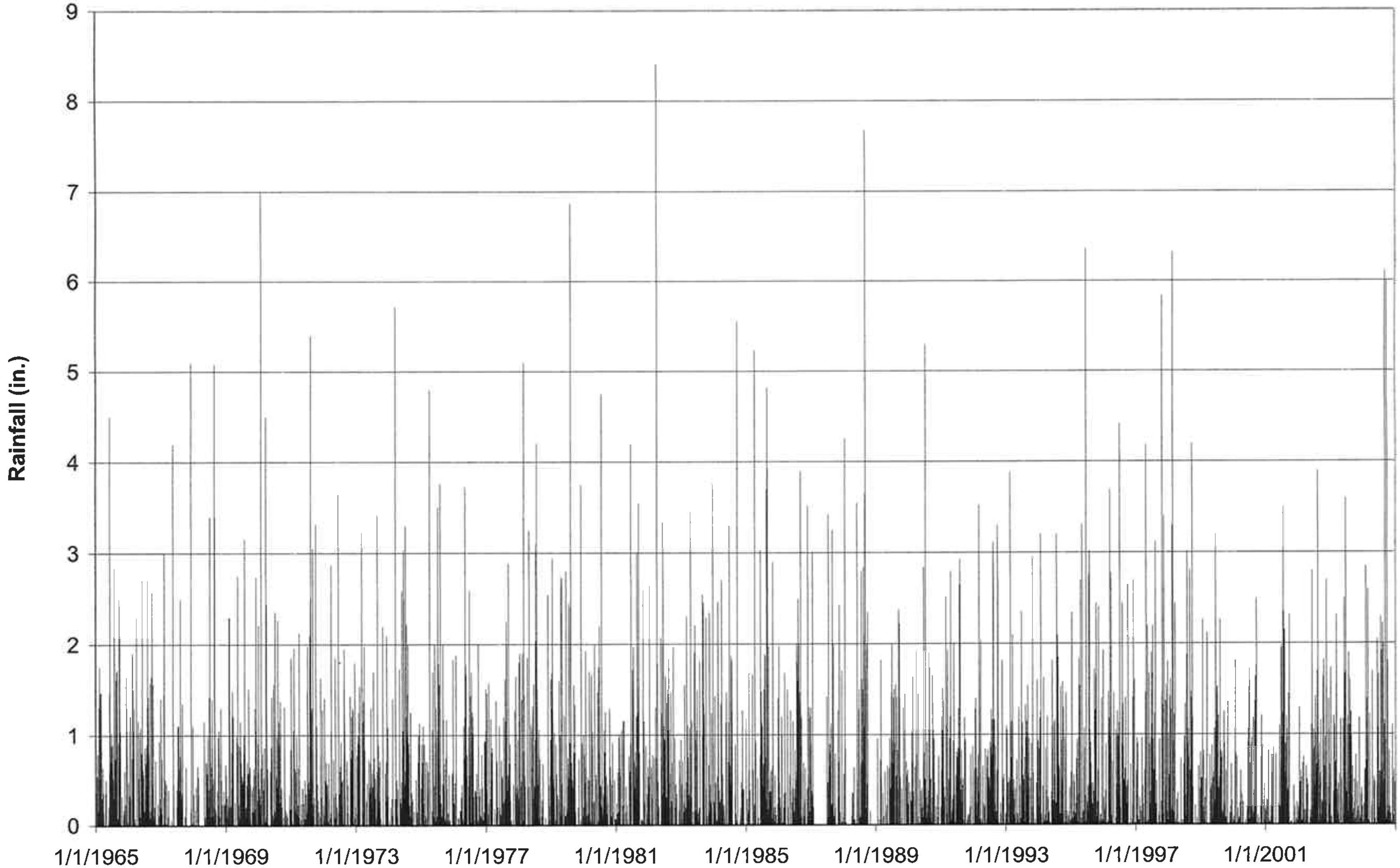
Wekiva Tower Monthly Rainfall Totals



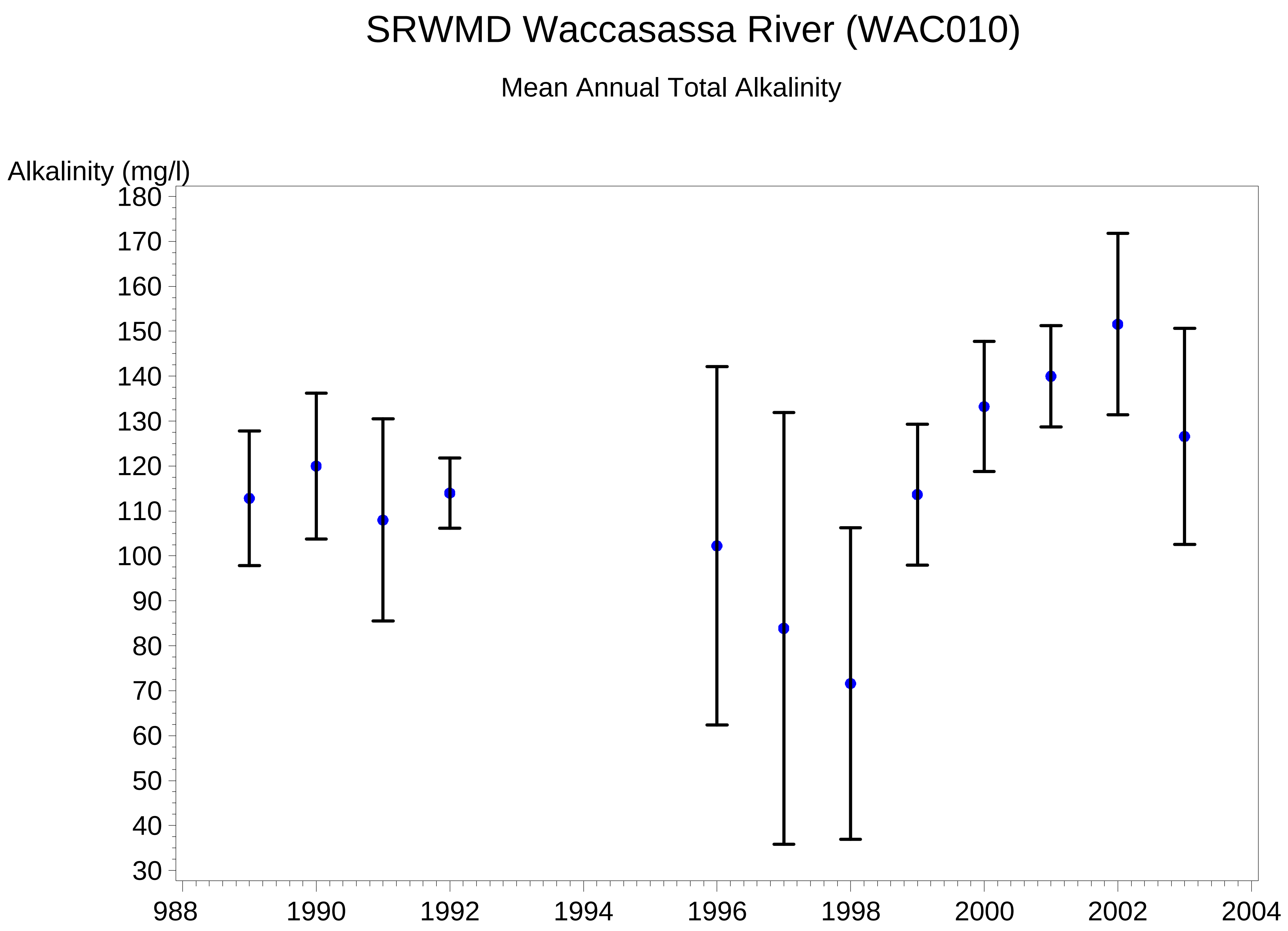
Lebanon Tower Monthly Rainfall Totals

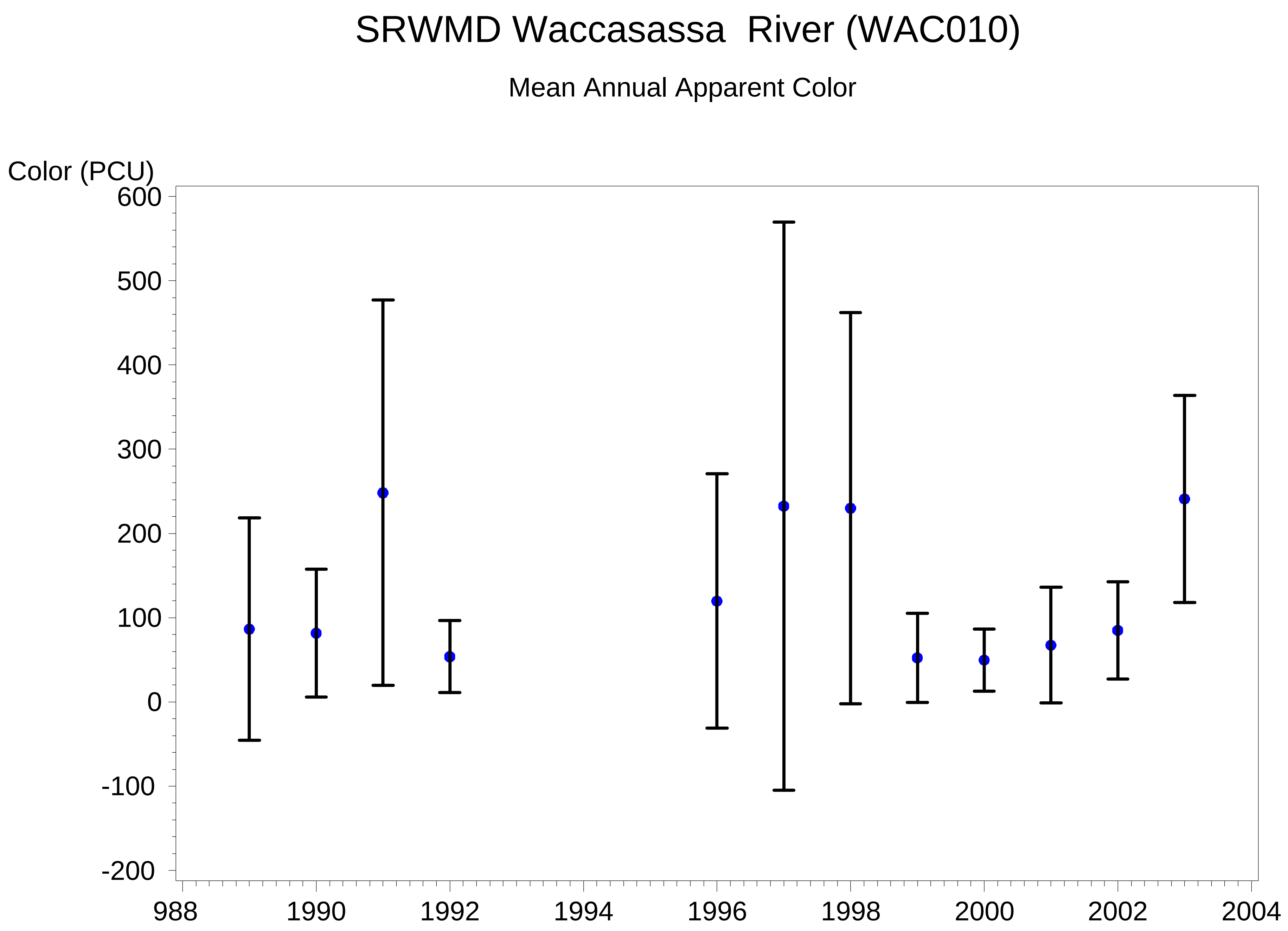


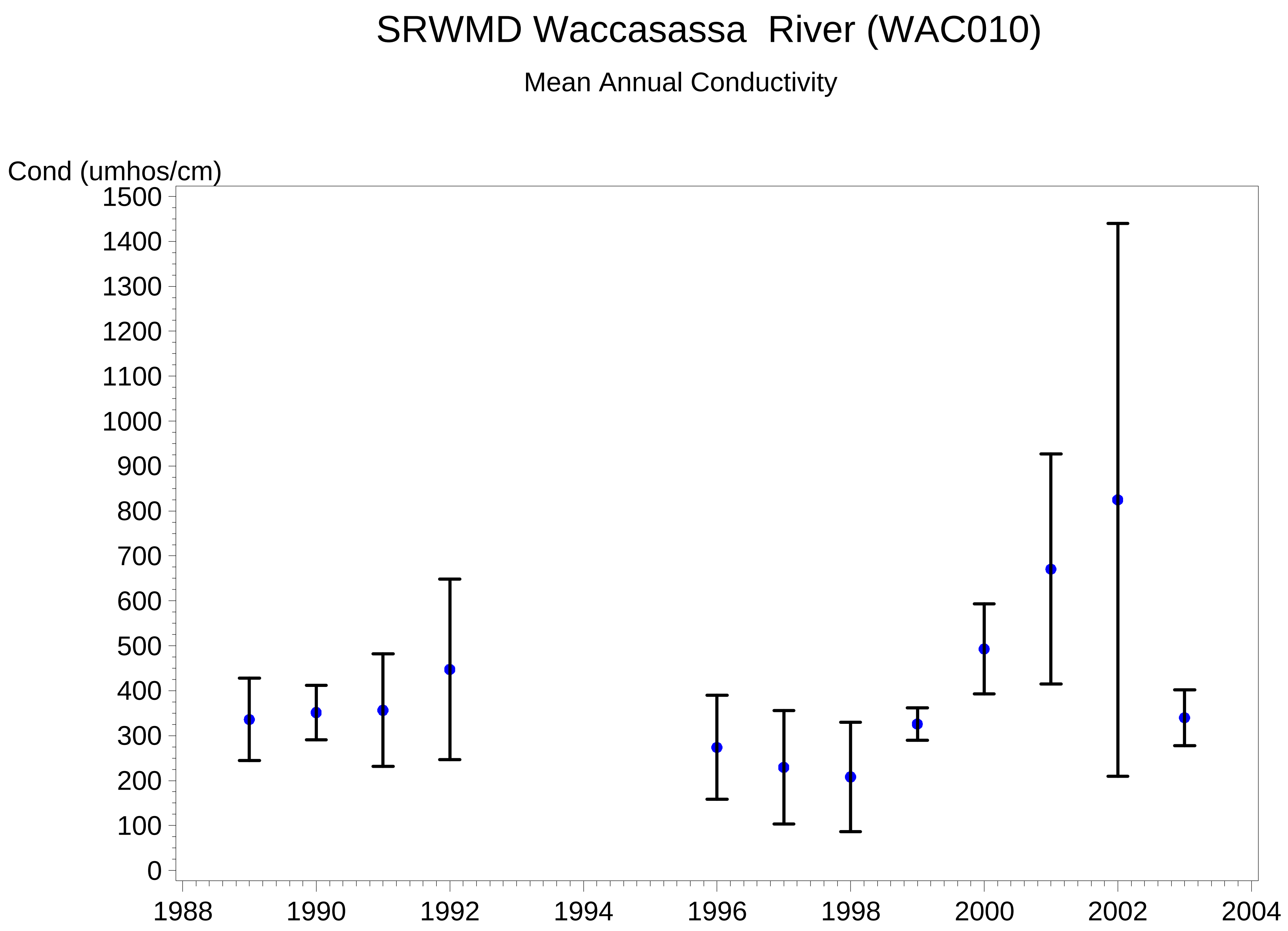
Usher Tower Daily Rainfall

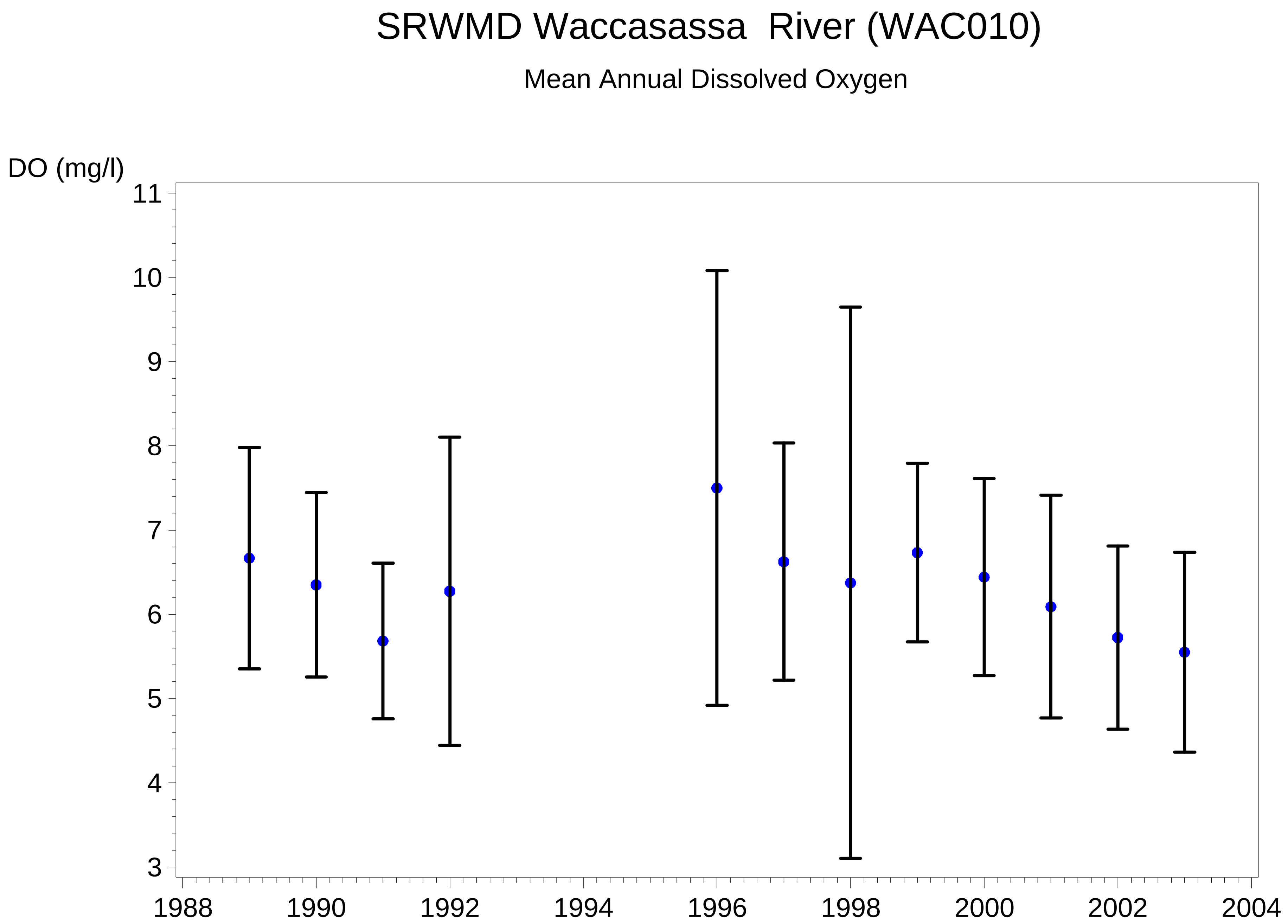


APPENDIX D

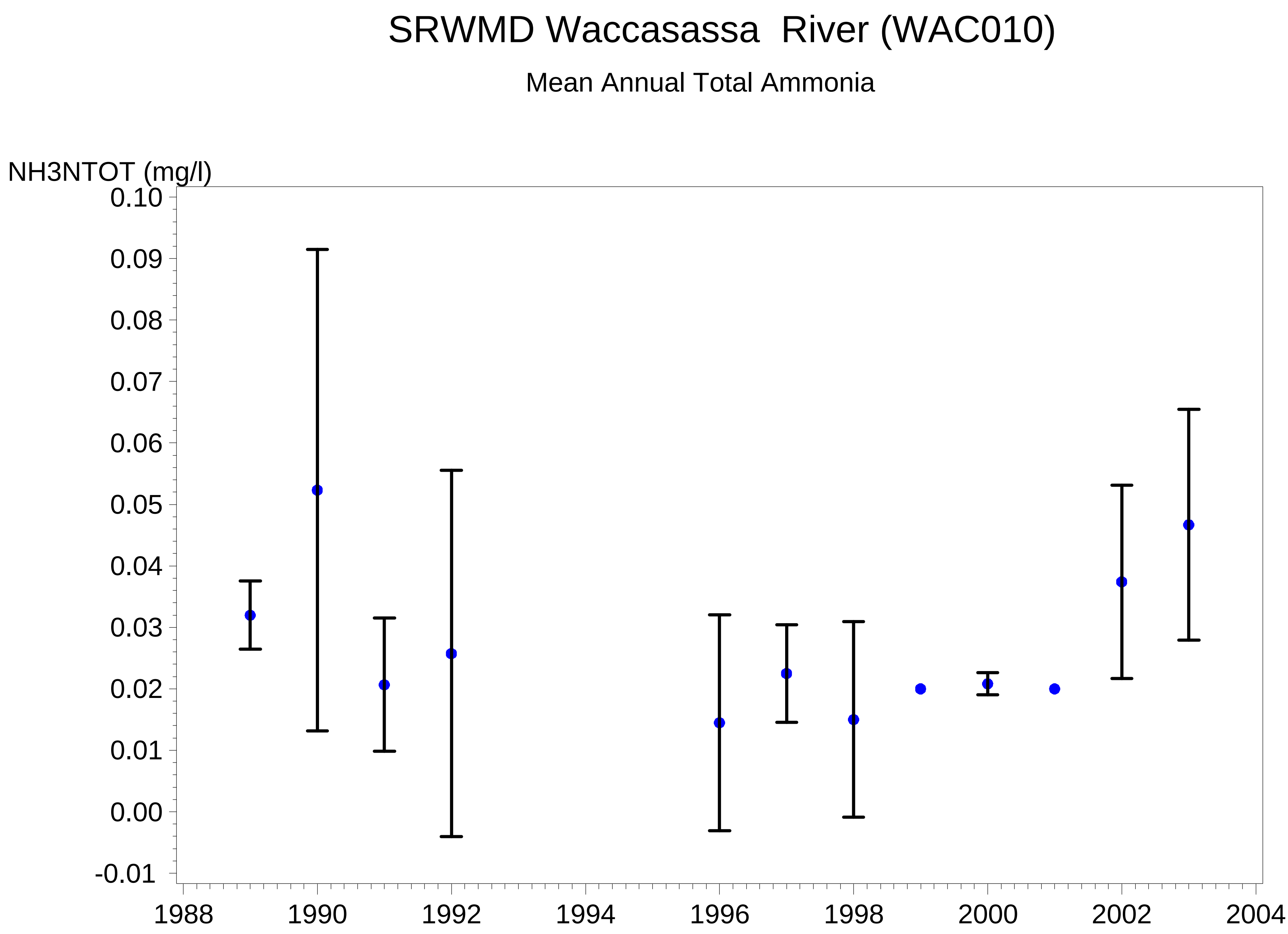

SRWMD Waccasassa River (WAC010)
Mean Annual Total Alkalinity
Alkalinity (mg/l)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
988
1990
1992
1994
1996
1998
2000
2002
2004

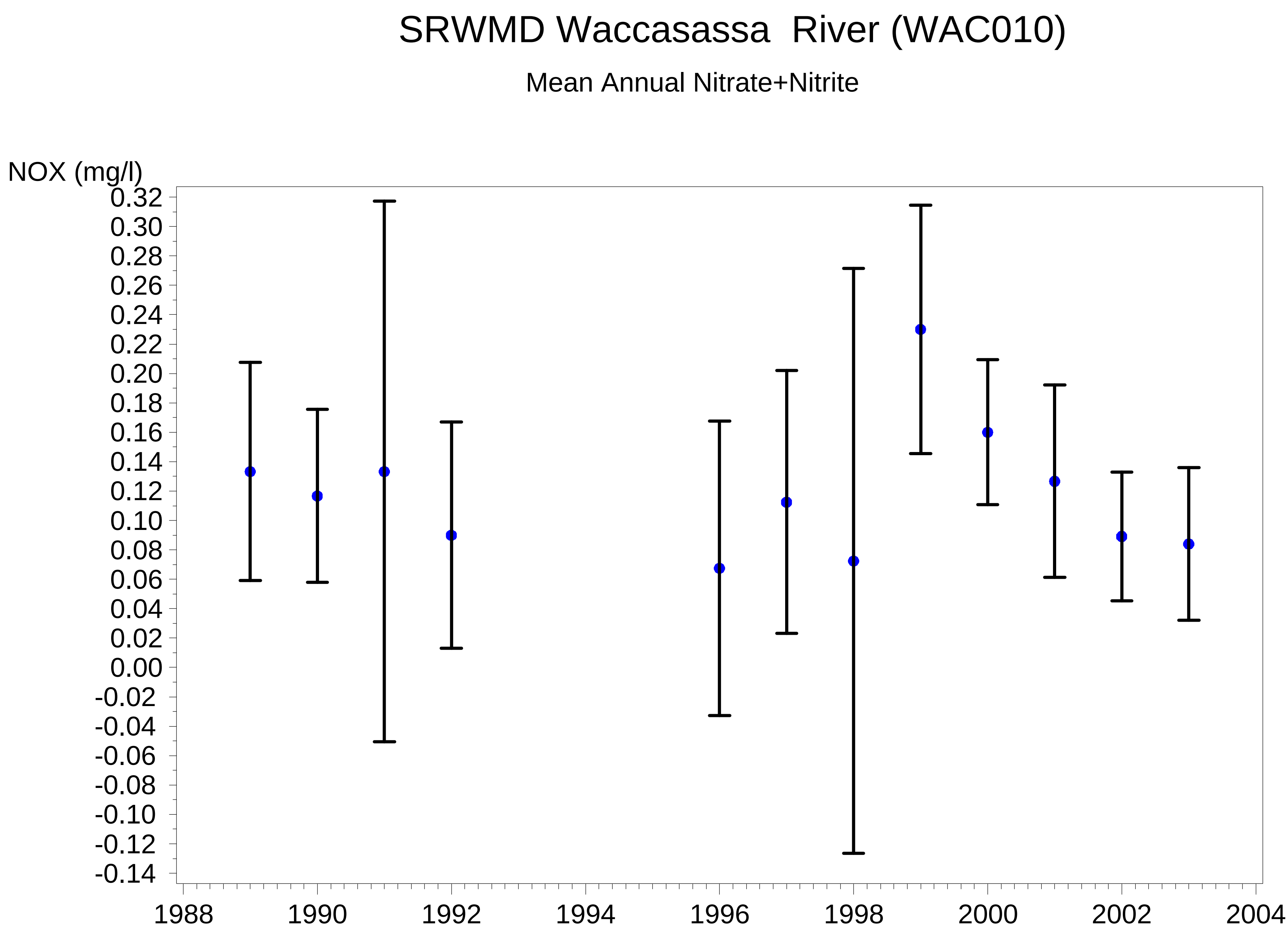

SRWMD Waccasassa River (WAC010)
Mean Annual Apparent Color
Color (PCU)
600
500
400
300
200
100
0
-100
-200
988
1990
1992
1994
1996
1998
2000
2002
2004

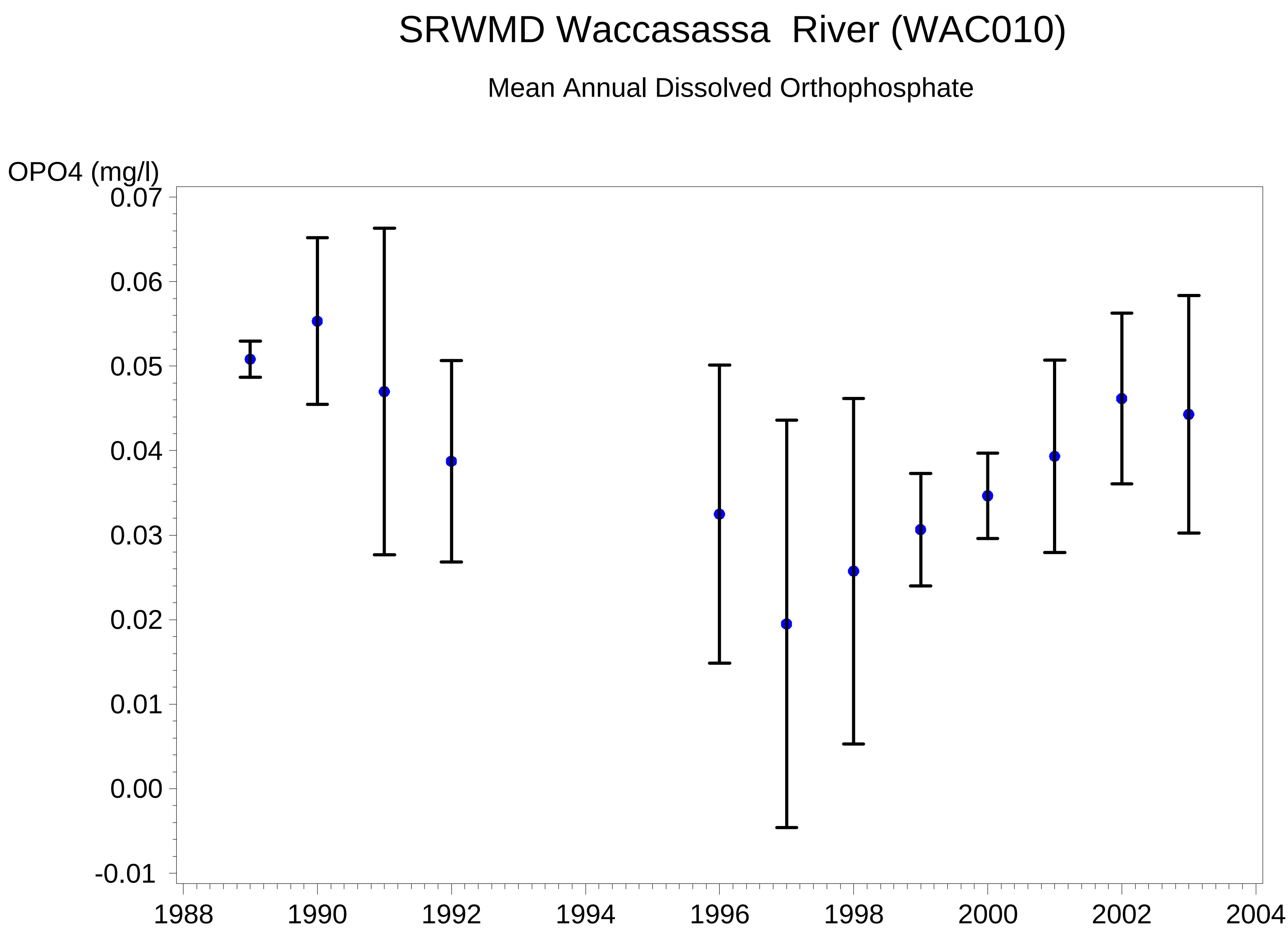

SRWMD Waccasassa River (WAC010)
Mean Annual Conductivity
Cond (umhos/cm)
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
1988
1990
1992
1994
1996
1998
2000
2002
2004

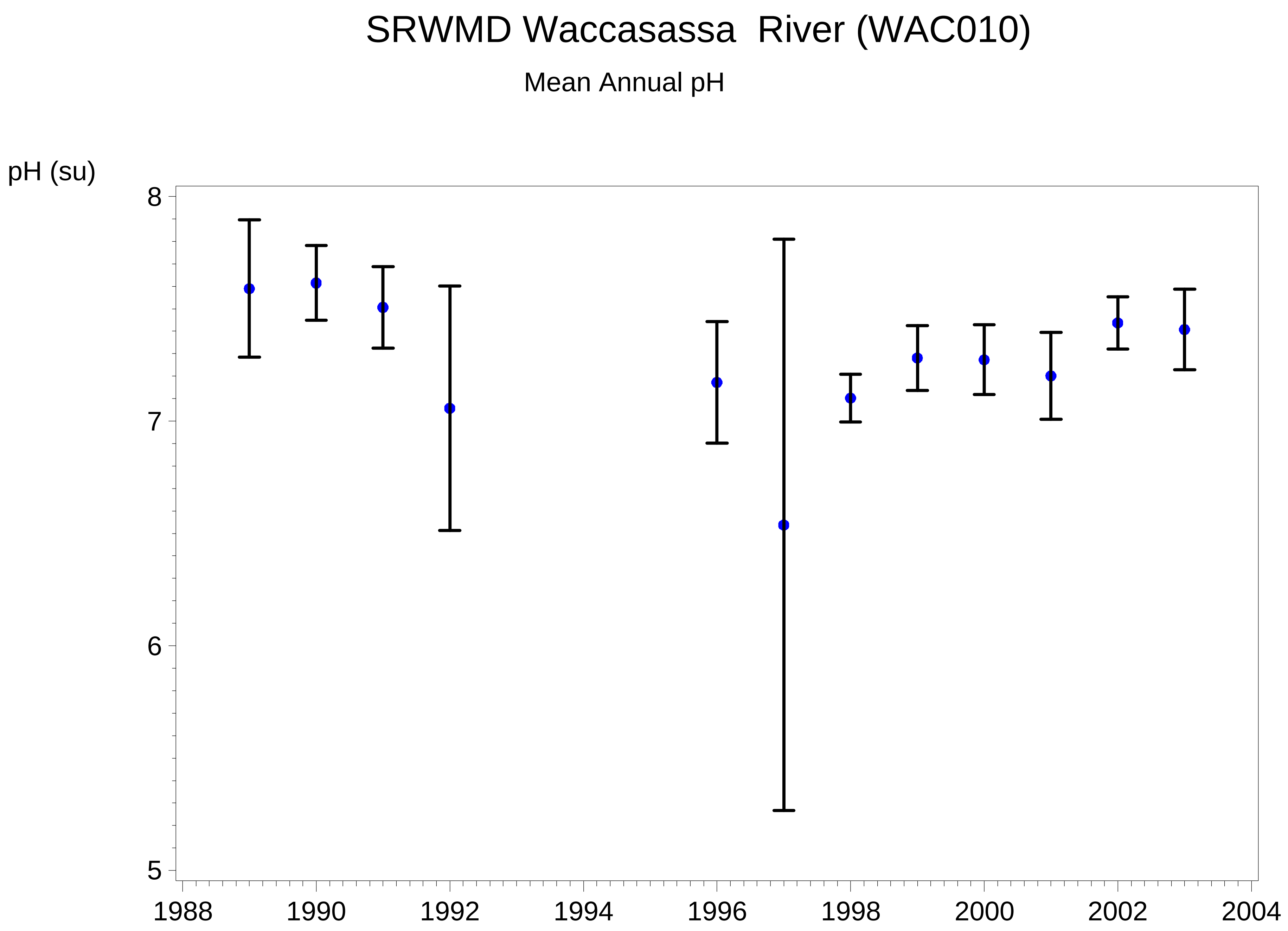


SRWMD Waccasassa River (WAC010)
Mean Annual Dissolved Oxygen
DO (mg/l)
11
10
9
8
7
6
5
4
3
1988
1990
1992
1994
1996
1998
2000
2002
2004

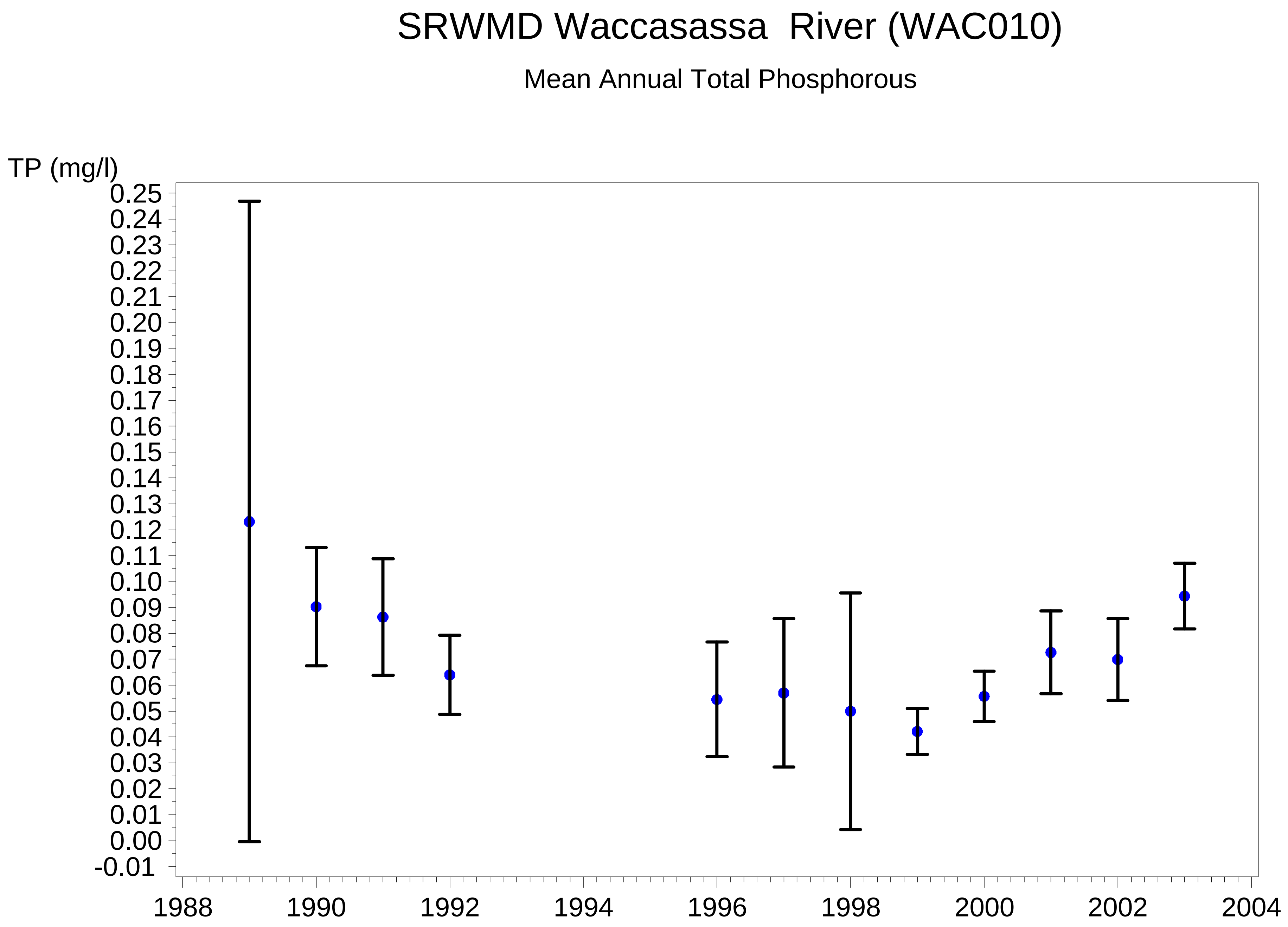

SRWMD Waccasassa River (WAC010)
Mean Annual Total Ammonia
NH3NTOT (mg/l)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
1988
1990
1992
1994
1996
1998
2000
2002
2004


SRWMD Waccasassa River (WAC010)
Mean Annual Nitrate+Nitrite
NOX (mg/l)
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-0.12
-0.14
1988
1990
1992
1994
1996
1998
2000
2002
2004

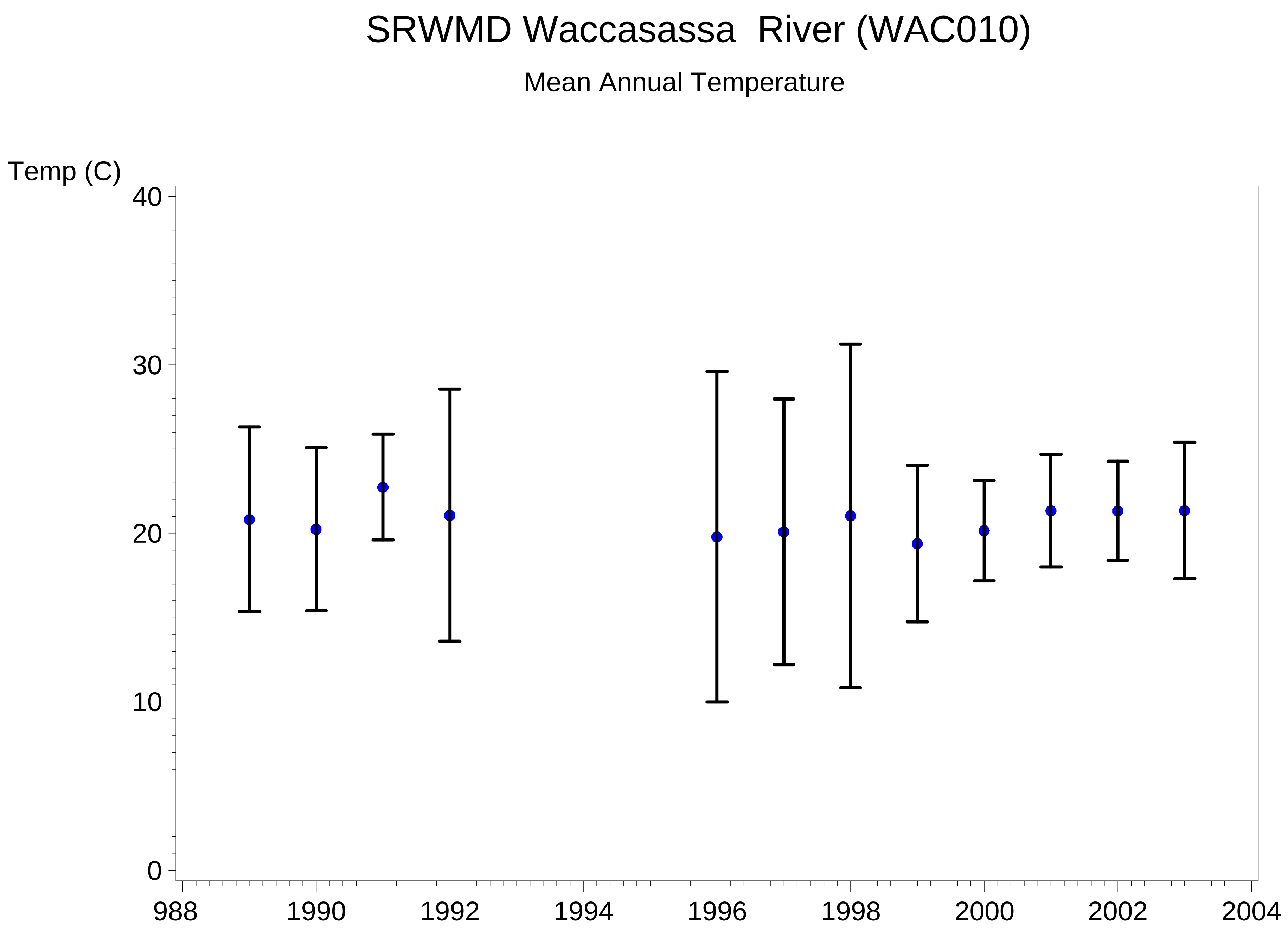

SRWMD Waccasassa River (WAC010)
Mean Annual Dissolved Orthophosphate
OPO4 (mg/l)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
1988
1990
1992
1994
1996
1998
2000
2002
2004

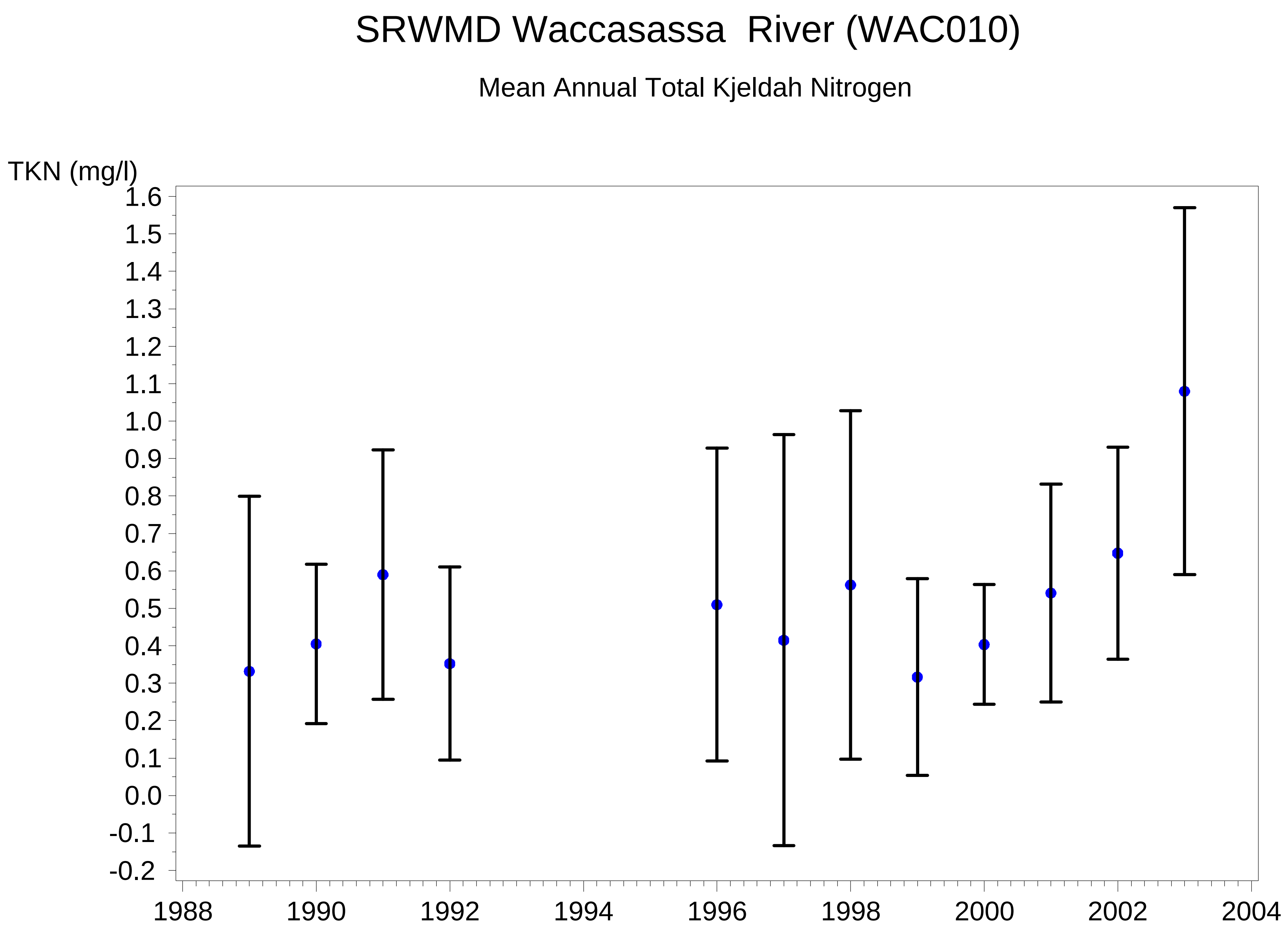


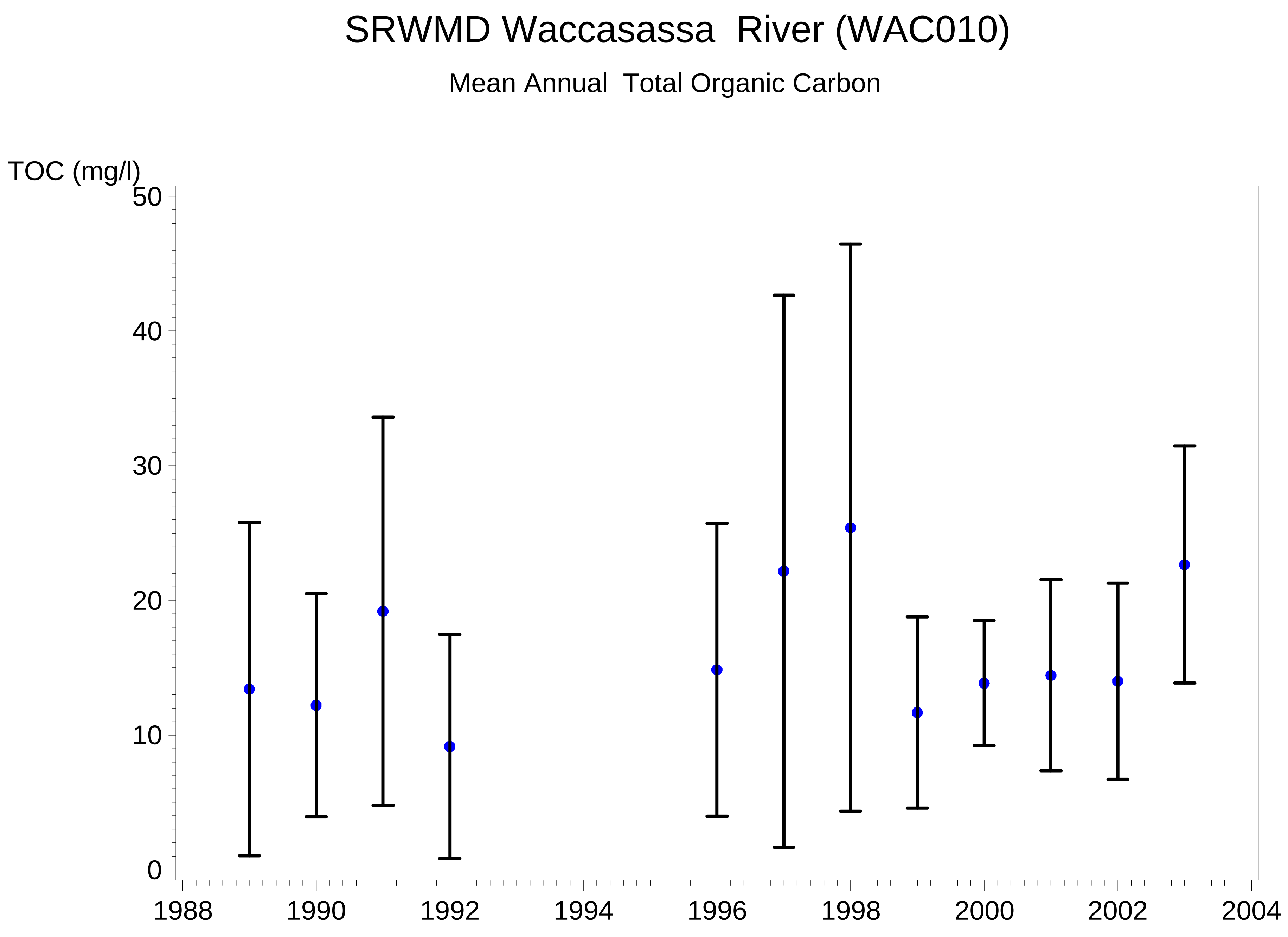
SRWMD Waccasassa River (WAC010)
Mean Annual pH
pH (su)
8
7
6
5
1988
1990
1992
1994
1996
1998
2000
2002
2004



SRWMD Waccasassa River (WAC010)
Mean Annual Total Phosphorous
TP (mg/l)
0.25
0.24
0.23
0.22
0.21
0.20
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
1988
1990
1992
1994
1996
1998
2000
2002
2004

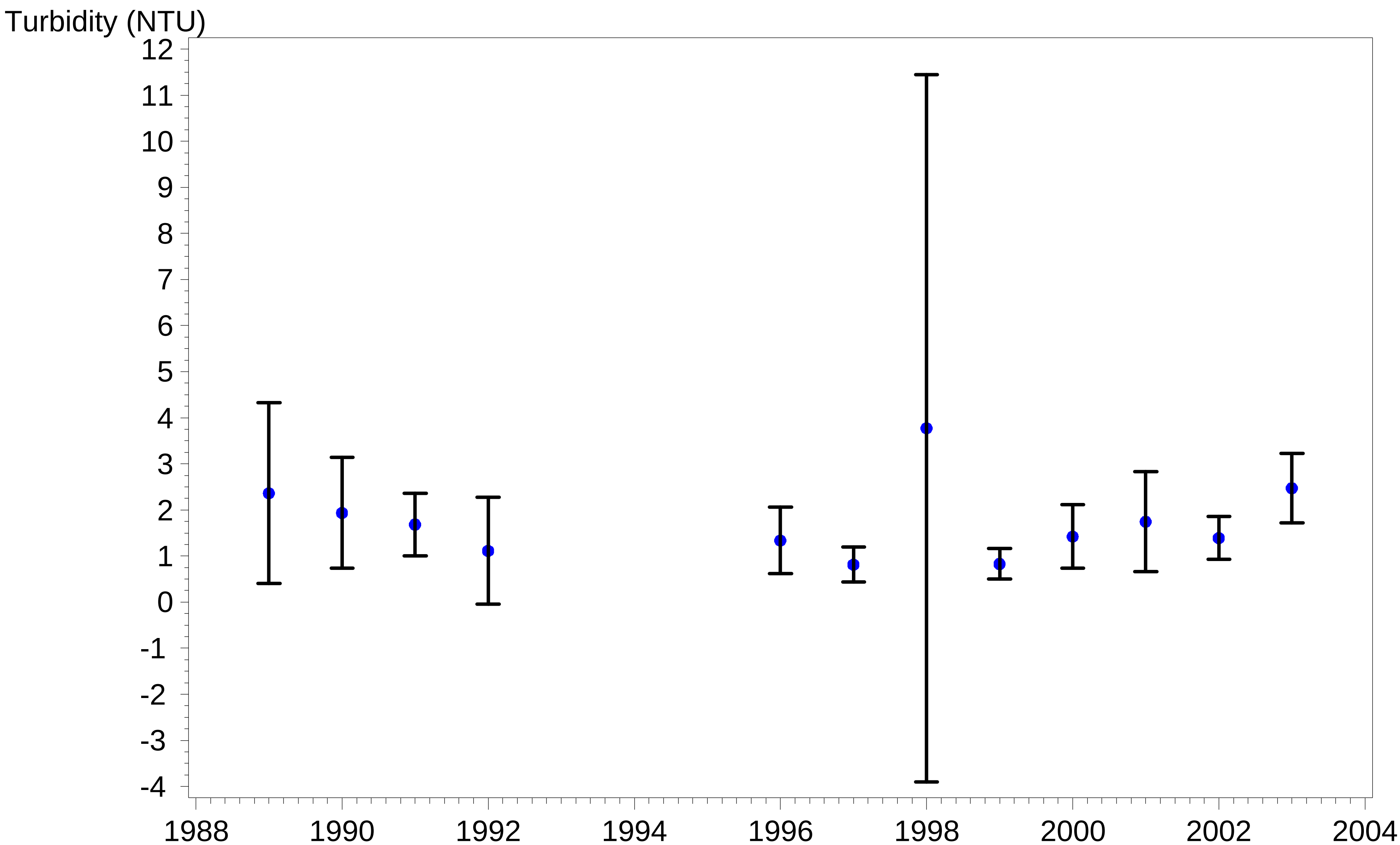

SRWMD Waccasassa River (WAC010)
Mean Annual Temperature
Temp (C)
40
30
20
10
0
988
1990
1992
1994
1996
1998
2000
2002
2004


SRWMD Waccasassa River (WAC010)
Mean Annual Total Kjeldah Nitrogen
TKN (mg/l)
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
1988
1990
1992
1994
1996
1998
2000
2002
2004


SRWMD Waccasassa River (WAC010)
Mean Annual Total Organic Carbon
TOC (mg/l)
0
10
20
30
40
50
1988
1990
1992
1994
1996
1998
2000
2002
2004

SRWMD Waccasassa River (WAC010)

Mean Annual Turbidity



APPENDIX E

Appendix E-1 Surface salinity for each station, date and time of sample for data collected in 2005 by the SWFWMD.

Station	Date	Surface salinity at high tide	Water level at sample time	Time of high tide sample	Surface salinity at low tide	Water level at sample time	Time of low tide sample	Time of high tide at Cedar Key	Water Level at CK high tide
WR000	10/26/2004	0.14	2.5	1612	0.11	0.7	852	12:42	4.27
WR000	11/29/2004	0.18	2.8	1616	0.16	-0.4	915	16:06	2.83
WR000	12/29/2004	0.16	2.8	1548	0.15	-0.6	923	16:18	2.77
WR000	1/24/2005	0.17	1.9	1618	0.16	0	948	15:24	2.28
WR000	2/28/2005	0.32	3.4	1521	0.26	0.4	839	16:00	4.01
WR000	3/21/2005	0.17	2	1439	0.16	1.6	915	13:12	3.04
WR000	4/14/2005	0.11	3.2	1508	0.11	1.7	952	16:00	3.55
WR000	5/19/2005	0.12	2.5	918	0.13	2.25	1408	10:42	3.83
WR000	6/23/2005	0.1	4.2	1350	0.1	1.8	859	13:48	4.83
WR000	7/20/2005	0.12	3.1	1515	0.09	2.4	850	12:00	5.02
WR050	10/26/2004	0.38	2.6	1557	0.12	0.8	920	12:42	4.27
WR050	11/29/2004	0.28	2.8	1605	0.18	-0.3	938	16:06	2.83
WR050	12/29/2004	0.2	2.8	1537	0.16	-0.6	935	16:18	2.77
WR050	1/24/2005	0.27	2.1	1606	0.17	0.5	1009	15:24	2.28
WR050	2/28/2005	0.98	3.3	1500	0.47	0.3	852	16:00	4.01
WR050	3/21/2005	0.19	2.2	1426	0.17	1.75	930	13:12	3.04
WR050	4/14/2005	0.11	3.1	1453	0.11	1.6	1007	16:00	3.55
WR050	5/19/2005	0.12	2.6	926	0.17	2.4	1356	10:42	3.83
WR050	6/23/2005	0.11	4.1	1336	0.1	1.9	909	13:48	4.83
WR050	7/20/2005	0.48	3.25	1502	0.09	2.5	904	12:00	5.02
WR100	10/26/2004	1.02	2.8	1546	0.12	1.3	938	12:42	4.27
WR100	11/29/2004	0.46	2.9	1553	0.18	-0.2	955	16:06	2.83
WR100	12/29/2004	0.22	2.7	1524	0.15	-0.6	949	16:18	2.77
WR100	1/24/2005	1.04	2.2	1551	0.17	0.7	1022	15:24	2.28
WR100	2/28/2005	1.68	3.25	1444	0.66	0.3	906	16:00	4.01
WR100	3/21/2005	0.31	2.3	1411	0.17	1.75	937	13:12	3.04
WR100	4/14/2005	0.11	3	1439	0.11	1.6	1022	16:00	3.55
WR100	5/19/2005	0.14	2.7	935	0.38	2.5	1342	10:42	3.83
WR100	6/23/2005	0.11	4	1324	0.1	1.9	923	13:48	4.83
WR100	7/20/2005	1.32	3.4	1447	0.09	2.6	917	12:00	5.02
WR141	10/26/2004	3.11	3	1534	0.14	1.5	1006	12:42	4.27
WR141	11/29/2004	0.8	2.9	1539	0.24	-0.1	1011	16:06	2.83
WR141	12/29/2004	0.3	2.7	1514	0.18	-0.5	1002	16:18	2.77
WR141	1/24/2005	2.47	2.3	1536	0.19	0.7	1036	15:24	2.28
WR141	2/28/2005	1.85	3.2	1427	1.55	0.3	920	16:00	4.01
WR141	3/21/2005	0.65	2.4	1358	0.19	1.9	947	13:12	3.04
WR141	4/14/2005	0.13	2.9	1427	0.13	1.7	1037	16:00	3.55
WR141	6/23/2005	0.12	3.9	1311	0.11	2	936	13:48	4.83
WR141	7/20/2005	2.37	3.6	1429	0.1	2.7	932	12:00	5.02
WR191	10/26/2004	5.86	3.1	1521	0.14	1.8	1030	12:42	4.27
WR191	11/29/2004	1.86	2.8	1522	0.3	0	1030	16:06	2.83

WR191	12/29/2004	1.11	2.6	1459	0.22	-0.5	1015	16:18	2.77
WR191	1/24/2005	5.8	2.3	1520	0.22	0.8	1050	15:24	2.28
WR191	2/28/2005	5.28	3	1412	3.4	0.3	936	16:00	4.01
WR191	3/21/2005	2.96	2.5	1343	0.22	2	956	13:12	3.04
WR191	4/14/2005	0.14	2.8	1414	0.14	1.7	1047	16:00	3.55
WR191	6/23/2005	0.17	3.8	1258	0.11	2	945	13:48	4.83
WR191	7/20/2005	5.4	3.8	1411	0.1	2.9	948	12:00	5.02
WR192	10/26/2004	5.66	3.2	1508	0.61	2.3	1055	12:42	4.27
WR192	11/29/2004	0.95	2.7	1504	0.38	0.1	1047	16:06	2.83
WR192	12/29/2004	0.58	2.5	1447	0.26	-0.4	1033	16:18	2.77
WR192	1/24/2005	4.33	2.4	1501	0.27	1.3	1111	15:24	2.28
WR192	2/28/2005	5.22	2.9	1358	6.76	0.3	1000	16:00	4.01
WR192	3/21/2005	2.85	2.6	1329	0.62	2.2	1009	13:12	3.04
WR192	4/14/2005	0.17	2.7	1359	0.15	1.7	1103	16:00	3.55
WR192	6/23/2005	0.2	3.8	1248	0.14	2.1	1000	13:48	4.83
WR192	7/20/2005	4.3	3.9	1356	0.17	3	1006	12:00	5.02
WR241	10/26/2004	7.97	3.3	1457	0.47	2.4	1116	12:42	4.27
WR241	11/29/2004	2.72	2.7	1449	0.41	0.2	1104	16:06	2.83
WR241	12/29/2004	0.62	2.4	1430	0.29	-0.3	1046	16:18	2.77
WR241	1/24/2005	6.38	2.5	1450	0.43	1.5	1127	15:24	2.28
WR241	2/28/2005	5.65	2.7	1341	3.85	0.5	1049	16:00	4.01
WR241	3/21/2005	5.26	2.6	1311	0.52	2.3	1022	13:12	3.04
WR241	4/14/2005	0.2	2.6	1345	0.16	1.7	1115	16:00	3.55
WR241	5/19/2005	9.8	3	1239	1.01	2.9	1020	10:42	3.83
WR241	6/23/2005	0.24	3.7	1234	0.14	2.2	1010	13:48	4.83
WR241	7/20/2005	5.83	4	1337	0.13	3.2	1017	12:00	5.03
WR290	10/26/2004	9.5	3.4	1444	1.92	2.7	1138	12:42	4.27
WR290	11/29/2004	3.88	2.5	1414	0.74	0.3	1118	16:06	2.83
WR290	12/29/2004	2.31	2.3	1409	0.45	-0.1	1104	16:18	2.77
WR290	1/24/2005	6.8	2.5	1437	0.72	1.6	1137	15:24	2.28
WR290	2/28/2005	8.49	2.5	1326	5.7	0.75	1107	16:00	4.01
WR290	3/21/2005	7.22	2.7	1255	2.11	2.4	1035	13:12	3.04
WR290	4/14/2005	0.19	2.5	1332	0.18	1.8	1131	16:00	3.55
WR290	5/19/2005	11.62	3.1	1226	3.39	3	1034	10:42	3.83
WR290	6/23/2005	0.3	3.5	1217	0.18	2.3	1025	13:48	4.83
WR290	7/20/2005	6.2	4.1	1319	0.25	3.3	1035	12:00	5.02
WR360	10/26/2004	10.56	3.4	1428	4.11	3	1205	12:42	4.27
WR360	11/29/2004	7.44	2.2	1348	1.7	0.5	1133	16:06	2.83
WR360	12/29/2004	4.74	2	1346	1.64	0	1113	16:18	2.77
WR360	1/24/2005	8	2.6	1422	3.19	1.9	1155	15:24	2.28
WR360	2/28/2005	11.01	2.4	1306	8.21	1	1123	16:00	4.01
WR360	3/21/2005	10.74	2.75	1238	6.28	2.5	1104	13:12	3.04
WR360	4/14/2005	0.36	2.4	1316	0.31	1.8	1147	16:00	3.55
WR360	5/19/2005	12.56	3.2	1210	9.75	3.1	1047	10:42	3.83
WR360	6/23/2005	0.78	3.4	1208	0.36	2.4	1037	13:48	4.83
WR360	7/20/2005	6.71	4.2	1258	0.95	3.5	1052	12:00	5.02
WR447	10/26/2004	12.03	3.5	1401	7.54	3.3	1228	12:42	4.27
WR447	11/29/2004	7.27	1.9	1311	4.97	0.95	1200	16:06	2.83

WR447	12/29/2004	8.87	1.7	1333	4.87	0.2	1130	16:18	2.77
WR447	1/24/2005	10.05	2.7	1400	5.57	2	1208	15:24	2.28
WR447	2/28/2005	14.03	2	1251	13.38	1.2	1147	16:00	4.01
WR447	3/21/2005	13.1	2.75	1225	10.37	2.6	1114	13:12	3.04
WR447	4/14/2005	1.14	2.3	1304	1.45	1.9	1206	16:00	3.55
WR447	5/19/2005	13.17	3.2	1200	12.46	3.1	1102	10:42	3.83
WR447	6/23/2005	1.59	3.1	1145	1.09	2.5	1052	13:48	4.84
WR447	7/20/2005	7.96	4.15	1235	3.88	3.7	1115	12:00	5.02
WR622	11/29/2004	15.63	1.5	1246	14.02	1.1	1220	16:06	2.84
WR622	12/29/2004	18.23	1.4	1258	13.85	0.5	1201	16:18	2.77
WR622	1/24/2005	18.68	2.5	1334	12.96	2.3	1248	15:24	2.28
WR622	2/28/2005	18.87	1.8	1236	18.4	1.3	1204	16:00	4.01
WR622	3/21/2005	18.55	2.8	1159	17.94	2.7	1131	13:12	3.04
WR622	4/14/2005	6.8	2.1	1249	7.15	2	1220	16:00	3.55
WR622	6/23/2005	11.02	2.9	1132	12.05	2.6	1105	13:48	4.83
WR622	7/20/2005	13.83	4	1200	12.78	3.8	1130	12:00	5.02

Appendix E-2 Surface salinity for each station, date and time of sample for data collected in 1985 by the SWFWMD.

DATE	Station	Surface salinity at high tide sample	Time of high tide sample	Surface salinity at low tide sample	Time of low tide sample
5-Feb-85	WCA1	0.18	1710		
17-Apr-85	WCA1	0.02	1503		
23-May-85	WCA1			0.09	1205
11-Jun-85	WCA1	0.36	1129		
20-Jun-85	WCA1	0.58	1732		
31-Jul-85	WCA1	0.51	1543		
11-Aug-85	WCA1	0.12	1142		
13-Sep-85	WCA1	0.03	1424		
23-Oct-85	WCA1	0.42	1253		
8-Dec-85	WCA1	0.08	1253		
5-Feb-85	WCA2	3.36	1650		
17-Apr-85	WCA2	0.02	1452		
23-May-85	WCA2	12.40	1648	0.75	1145
11-Jun-85	WCA2	5.05	1112		
20-Jun-85	WCA2	0.26	1717		
31-Jul-85	WCA2	3.73	1524		
11-Aug-85	WCA2	0.21	1131		
13-Sep-85	WCA2	0.08	1418		
23-Oct-85	WCA2	7.17	1240		
8-Dec-85	WCA2	1.10	1239		
5-Feb-85	WCA3	9.74	1636		
17-Apr-85	WCA3	0.05	1443		
23-May-85	WCA3	17.06	1632	4.09	1124

11-Jun-85	WCA3	12.35	1057		
20-Jun-85	WCA3	10.01	1655		
31-Jul-85	WCA3	9.50	1508		
11-Aug-85	WCA3	0.76	1115		
13-Sep-85	WCA3	0.44	1408		
23-Oct-85	WCA3	15.04	1227		
8-Dec-85	WCA3	4.73	1225		
5-Feb-85	WCA4	11.60	1605		
17-Apr-85	WCA4	0.12	1417		
23-May-85	WCA4	17.67	1625	6.88	1114
11-Jun-85	WCA4	14.51	1032		
20-Jun-85	WCA4	13.65	1642		
22-Jul-85	WCA4			0.58	1305
31-Jul-85	WCA4	11.82	1457		
11-Aug-85	WCA4	4.09	1043		
13-Sep-85	WCA4	0.71	1404		
23-Oct-85	WCA4	17.19	1205		
8-Dec-85	WCA4	7.73	1156		
5-Feb-85	WCA5	17.25	1553		
17-Apr-85	WCA5	1.94	1357		
23-May-85	WCA5	19.66	1607	12.40	1056
11-Jun-85	WCA5	20.20	1022		
20-Jun-85	WCA5	15.65	1548		
22-Jul-85	WCA5			2.95	1255
31-Jul-85	WCA5	14.12	1445		
11-Aug-85	WCA5	9.50	1032		
13-Sep-85	WCA5	4.97	1353		
23-Oct-85	WCA5	19.43	1159		
8-Dec-85	WCA5	11.70	1142		
5-Feb-85	WCA6	19.38	1520		
17-Apr-85	WCA6	10.08	1340		
23-May-85	WCA6	20.34	1545	17.00	1035
11-Jun-85	WCA6	23.92	1015		
20-Jun-85	WCA6	15.45	1455		
22-Jul-85	WCA6			8.09	1245
31-Jul-85	WCA6	15.11	1427		
11-Aug-85	WCA6	10.59	1015		
13-Sep-85	WCA6	6.64	1341		
23-Oct-85	WCA6	20.01	1150		
8-Dec-85	WCA6	17.29	1135		
5-Feb-85	WCA7	19.98	1500		
17-Apr-85	WCA7	14.01	1318		
23-May-85	WCA7	21.52	1537	18.22	1025
11-Jun-85	WCA7	25.36	1000		
20-Jun-85	WCA7	17.67	1445		
22-Jul-85	WCA7			9.71	1234
31-Jul-85	WCA7	16.32	1419		
11-Aug-85	WCA7	10.31	1000		

13-Sep-85	WCA7	5.85	1334		
23-Oct-85	WCA7	21.45	1141		
8-Dec-85	WCA7	20.39	1123		
5-Feb-85	WCA8	24.02	1455		
17-Apr-85	WCA8	17.81	1309		
11-Jun-85	WCA8	27.84	953		
20-Jun-85	WCA8	19.93	1433		
22-Jul-85	WCA8			13.39	1227
31-Jul-85	WCA8	18.08	1409		
11-Aug-85	WCA8	11.73	955		
13-Sep-85	WCA8	9.14	1326		
23-Oct-85	WCA8	22.58	1133		
8-Dec-85	WCA8	21.65	1115		
5-Feb-85	WCA9	25.45	1449		
17-Apr-85	WCA9	18.51	1302		
11-Jun-85	WCA9	27.79	943		
20-Jun-85	WCA9	19.79	1422		
22-Jul-85	WCA9			14.98	1220
31-Jul-85	WCA9	20.14	1358		
11-Aug-85	WCA9	14.56	945		
23-Oct-85	WCA9	24.23	1128		
8-Dec-85	WCA9	23.20	1109		
23-May-85	WCAA0	4.04	1712		
11-Jun-85	WCAA0	0.19	1150		
20-Jun-85	WCAA0	0.57	1739		
31-Jul-85	WCAA0	0.42	1553		
23-Oct-85	WCAA0	0.26	1311		
5-Feb-85	WCAA1	1.27	1658		
23-May-85	WCAA1	10.09	1657	0.27	1154
11-Jun-85	WCAA1	3.22	1119		
20-Jun-85	WCAA1	2.34	1725		
31-Jul-85	WCAA1	1.69	1533		
23-Oct-85	WCAA1	2.57	1245		
5-Feb-85	WCAA2	5.84	1643		
23-May-85	WCAA2	14.71	1642	1.95	1133
11-Jun-85	WCAA2	7.15	1105		
20-Jun-85	WCAA2	6.34	1711		
31-Jul-85	WCAA2	5.98	1517		
23-Oct-85	WCAA2	10.92	1234		
8-Dec-85	WCAA2	1.87	1234		
5-Feb-85	WCAA3	10.83	1620		
17-Apr-85	WCAA3	0.08	1436		
11-Jun-85	WCAA3	15.09	1051		
22-Jul-85	WCAA3			0.37	1312
11-Aug-85	WCAA3	1.77	1105		
8-Dec-85	WCAA3	6.63	1210		
17-Apr-85	WCAA4	0.39	1406		
23-May-85	WCAA4	18.56	1617	9.17	1106

20-Jun-85	WCAA4	13.92	1606		
22-Jul-85	WCAA4			1.06	1300
11-Aug-85	WCAA4	7.12	1038		
13-Sep-85	WCAA4	1.63	1359		
8-Dec-85	WCAA4	8.62	1147		
17-Apr-85	WCAA5	3.31	1352		
23-May-85	WCAA5	18.90	1557	14.78	1046
20-Jun-85	WCAA5	15.18	1508		
22-Jul-85	WCAA5			4.70	1250
31-Jul-85	WCAA5	14.71	1437		
11-Aug-85	WCAA5	9.66	1025		
13-Sep-85	WCAA5	5.64	1347		
5-Feb-85	WCA10	26.89	1430		
17-Apr-85	WCA10	18.00	1218		
11-Jun-85	WCA10	27.11	930		
20-Jun-85	WCA10	22.43	1410		
31-Jul-85	WCA10	21.17	1350		
11-Aug-85	WCA10	19.13	925		
23-Oct-85	WCA10	24.13	1111		
8-Dec-85	WCA10	23.31	1052		

Appendix E-3 Regression summary for 2005 data estimating the effects of water level (TIDEFT) on isohaline location in the Waccasassa River.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	46.61117	23.30559	30.35	0.0016
Error	5	3.83919	0.76784		
Corrected Total	7	50.45036			

Root MSE	0.87626	R-Square	0.9239
Dependent Mean	1.77610	Adj R-Sq	0.8935
Coeff Var	49.33630		

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|	Type I SS
Intercept	0.86751	2.17638	0.40	0.7066	25.23632
Discharge700	-0.01678	0.00219	-7.65	0.0006	40.51027
TIDEFT	2.36273	0.83821	2.82	0.0372	6.10091

Appendix E-4 Results of regression analysis using combined 1985 and 2005 synoptic salinity surveys. Data from 2005 are adjusted to high tide.

---------------------------------- TIDE=HIGH isohaline=5 Sample_level=Surface ----------------------------------

Number of Observations Read	18
Number of Observations Used	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	57.72368	57.72368	52.31	<.0001
Error	16	17.65427	1.10339		
Corrected Total	17	75.37795			

Root MSE	1.05042	R-Square	0.7658
Dependent Mean	4.27879	Adj R-Sq	0.7512
Coeff Var	24.54957		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	6.45861	0.39003	16.56	<.0001
mean2	1	-0.00880	0.00122	-7.23	<.0001

---------------------------------- TIDE=HIGH isohaline=5 Sample_level=Surface ----------------------------------

Output Statistics

Obs	Dependent Variable	Predicted Value	Std Error Mean Predict	95% CL Mean		Residual	Std Error Residual	Student Residual	-2-1 0 1 2	Cook's D
1	7.9044	6.5378	0.3986	5.6929	7.3827	1.3666	0.972	1.406	|**	0.166
2	4.4904	6.0449	0.3477	5.3078	6.7821	-1.5546	0.991	-1.568	***|	0.151
3	5.3550	5.6401	0.3110	4.9808	6.2994	-0.2851	1.003	-0.284	|	0.004
4	5.9973	5.7985	0.3247	5.1101	6.4869	0.1988	0.999	0.199	|	0.002
5	5.2445	5.4332	0.2946	4.8088	6.0577	-0.1888	1.008	-0.187	|	0.001
6	6.4417	5.4464	0.2956	4.8199	6.0730	0.9953	1.008	0.987	|*	0.042
7	4.1441	4.0426	0.2497	3.5132	4.5720	0.1015	1.020	0.0995	|	0.000
8	4.3754	5.0900	0.2718	4.5138	5.6662	-0.7146	1.015	-0.704	*|	0.018
9	6.9064	4.9712	0.2654	4.4084	5.5339	1.9352	1.016	1.904	|***	0.124
10	2.5726	4.1174	0.2486	3.5904	4.6444	-1.5448	1.021	-1.514	***|	0.068
11	3.4139	4.0558	0.2495	3.5269	4.5847	-0.6420	1.020	-0.629	*|	0.012
12	5.4442	4.1130	0.2486	3.5859	4.6401	1.3312	1.021	1.304	|**	0.050
13	2.5222	2.9248	0.3104	2.2668	3.5828	-0.4026	1.004	-0.401	|	0.008
14	6.2306	6.8899	0.4377	5.9619	7.8179	-0.6593	0.955	-0.690	*|	0.050
15	1.0081	1.3186	0.4783	0.3046	2.3326	-0.3105	0.935	-0.332	|	0.014
16	2.4987	2.3527	0.3636	1.5819	3.1236	0.1459	0.985	0.148	|	0.001
17	0.4539	1.4902	0.4582	0.5189	2.4615	-1.0363	0.945	-1.096	**|	0.141
18	2.0149	0.7509	0.5470	-0.4087	1.9105	1.2640	0.897	1.410	|**	0.370

Sum of Residuals	0
Sum of Squared Residuals	17.65427
Predicted Residual SS (PRESS)	22.61217

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